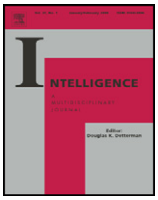
Intelligence 53 (2015) 138–144

Contents lists available at ScienceDirect

Intelligence



Intelligence and the psychological refractory period: A lateralized readiness potential study

Stefan J. Troche [a,*], Rebekka Indermühle [b], Hartmut Leuthold [c], Thomas H. Rammsayer [b,d]

[a] Department of Psychology and Psychotherapy, University of Witten/Herdecke, Witten, Germany
[b] Department of Psychology, University of Bern, Bern, Switzerland
[c] Department of Psychology, University of Tübingen, Tübingen, Germany
[d] Center for Cognition, Learning, and Memory, University of Bern, Bern, Switzerland

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 26 June 2015
Accepted 1 October 2015
Available online 30 October 2015

Keywords:
Intelligence
Psychological refractory period
Speed of information processing
Lateralized readiness potential

ABSTRACT

The psychological refractory period (PRP) refers to a delay of response times (RT) to the second of two stimuli when these stimuli are presented in rapid succession. If this limitation of rapidly processing the second stimulus contributes to the well-known differences in speed of information processing between individuals with higher and lower mental ability, individuals with lower mental ability should exhibit a more pronounced PRP effect than individuals with higher mental ability. Previous studies on this question, however, yielded inconsistent results. In the present study, we assessed mental ability-related differences in the PRP by measuring lateralized readiness potentials (LRPs) to separate premotor and motor aspects of speed of information processing in 95 individuals with higher and 95 individuals with lower mental ability. Although individuals with higher mental ability processed information faster than individuals with lower mental ability as indicated by shorter RTs and shorter premotor LRP latencies, the PRP effect was equally pronounced in both groups. These findings suggest that the processes underlying the PRP effect do not contribute to mental ability-related differences in speed of information processing. Rather, these differences seem to occur at an earlier stage of information processing such as stimulus encoding, stimulus analysis, or stimulus evaluation.

1. Introduction

One of the best established findings in the realm of experimental research on intelligence is the positive relationship between mental ability and speed of information processing as indicated by shorter response times (RTs) in individuals with higher compared to lower mental ability across a broad range of experimental tasks (Deary, 2000, 2012; Jensen, 1998, 2006; Sheppard & Vernon, 2008). Although correlation coefficients between RT and mental ability are of only moderate strength, commonly ranging between $r = -.20$ and $r = -.40$, this association is highly consistent. Common explanations of this relationship proceed from the assumption that so-called bottlenecks of information processing may contribute to mental ability-related differences in speed of information processing (cf., Jensen, 2006; Lee & Chabris, 2013; Salthouse, 1996).

A prominent bottleneck in sensorimotor information processing that has been investigated extensively in cognitive psychological research represents the psychological refractory period (PRP). In a standard PRP paradigm, where participants perform two choice-reaction tasks in rapid succession, the response to the second task stimulus (S2) is markedly delayed when it is presented with a very short stimulus onset asynchrony (SOA) of, for example, 100 ms after the first task stimulus (S1) compared to a long SOA of, for example, 800 ms (Jentzsch, Leuthold, & Ulrich, 2007). The shorter the SOA between S1 and S2 is, the more delayed are RTs to S2. This pattern of delayed RTs to S2 is referred to as the PRP effect, and is commonly taken to indicate that central bottleneck processing of S2 is postponed until the processing of S1 within this stage has been completed (Lien & Proctor, 2002; Marois & Ivanoff, 2005; Miller & Alderton, 2006; Pashler, 1994).

Psychophysiological studies employing the lateralized readiness potential (LRP) of the electroencephalogram (EEG) investigated the locus of PRP within the stream of information processing. If, for example, in choice-reaction tasks participants are asked to respond with the right or the left hand, a readiness potential can be derived from motor cortex areas several hundred milliseconds before a voluntary hand movement is executed. Reflecting the asymmetrical cortical activation of hand-specific lateralization processes, the LRP is larger contralateral than ipsilateral to the responding hand (Coles, 1989; Gratton, Coles, Sirevaag, Erikson, & Donchin, 1988). Furthermore, LRP provides two measures directly related to speed of information processing. On the one hand, the time interval between the onset of the LRP and completion of the overt motor response represents the time needed for central response organization and peripheral response execution. This time interval is referred to as the response-locked LRP (LRP-R) latency. On the other hand,

---

[*] Corresponding author at: Department of Psychology and Psychotherapy, University of Witten/Herdecke, Alfred-Herrhausen-Str. 50, D-58448 Witten, Germany.
E-mail address: stefan.troche@uni-wh.de (S.J. Troche).

http://dx.doi.org/10.1016/j.intell.2015.10.003
0160-2896/

the time interval between stimulus onset and onset of the LRP is referred to as stimulus-locked LRP (S-LRP) latency. S-LRP latency reflects the time required for premotor processing including stimulus encoding, stimulus analysis, stimulus evaluation, and response selection. Thus, the LRP approach allows for a separation of speed of premotor information processing from speed of motor processing (Masaki, Wild-Wall, Sangals, & Sommer, 2004). With regard to PRP, it has been shown that the PRP effect occurs at the stage of premotor information processing, as indicated by S-LRP latency, rather than at the stage of motor processing (Jentzsch et al., 2007; Osman & Moore, 1993; but see Lien, Ruthruff, Hsieh, & Yu, 2007). More specifically, S-LRP latencies for the second task were reported to increase with decreasing SOA reflecting the PRP effect, whereas SOA had no influence on LRP-R latencies. In the study by Jentzsch et al., (2007), SOA also had no effect on early perceptual components of the event-related potential so that these authors concluded that PRP probably occurs at the central stage of response selection (for similar conclusions see Han & Marois, 2013; Pashler, 1994; Ulrich & Miller, 2008).

Despite the significance of PRP for current cognitive psychology, studies on the relationship between PRP and mental ability are scant and yielded rather inconsistent results. The major focus of these studies was on whether the magnitude of the delay of RTs at shorter compared to longer SOAs, henceforth referred to as the PRP effect, was larger in individuals with lower mental ability than in individuals with higher mental ability. In a first study on this topic, we examined mental ability-related differences in the PRP effect of 80 university students (Indermühle, Troche, & Rammsayer, 2011). The 40 individuals with higher mental ability responded faster to both S1 and S2 compared to 40 individuals with lower mental ability. The increase in RT to S2 with decreasing SOA was of the same magnitude in both mental ability groups though. Consequently, the PRP effect (independent of the individual level of speed of information processing) seemed not to be mediated by mental ability. Also Laguë-Beauvais, Gagnon, Castonguay, and Bherer (2013) investigated the association between PRP and mental ability. For each of their 20 participants, they determined the PRP effect by subtracting mean RT to S2 in a condition with an SOA of 1000 ms between S1 and S2 from mean RT to S2 in a condition with an SOA of 15 ms. Then, the sample was divided into 10 individuals with a larger and 10 individuals with a smaller PRP effect. In a next step, scores on subtests of the Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1981) were compared between both PRP groups. Laguë-Beauvais et al., (2013) found that the group with the smaller PRP effect was faster on the subtest Symbol Search. For all other subtests (Similarities, Matrix Reasoning, Digit Span, Digit Symbol Coding, Letter-Number Sequence), individuals with a larger PRP effect did not differ significantly from those with a smaller PRP effect. This finding casts serious doubt on the notion of a functional relationship between the PRP effect and mental ability. Recently, Lee and Chabris (2013) reported faster RTs to S2 on a PRP task in 36 individuals with higher than in 34 individuals with lower mental ability. This mental ability-related difference was more pronounced in conditions with shorter compared to longer SOAs and, thus, suggests a larger PRP effect in individuals with lower compared to individuals with higher mental ability. Taken together, while the available studies on mental ability-related differences in the PRP effect confirm faster speed of information processing in individuals with higher than in individuals with lower mental ability, no consistent differences in the PRP effect were found between groups of different mental ability.

A possible reason for these inconsistencies might be seen in the use of behavioral RT measures which represent a compound of the time needed for premotor stimulus processing and motor processing (cf., Miller & Ulrich, 2013; Rammsayer & Stahl, 2007). As mentioned earlier, premotor stimulus processing includes stimulus encoding, stimulus analysis, and stimulus evaluation as well as response selection whereas motor processing comprises response organization and motor execution. Research on mental ability-related differences in speed of information processing indicates quite consistently that speed of premotor processing is related to mental ability. For example, it is well-known from studies on inspection time that the time required for stimulus encoding and stimulus analysis is shorter in individuals with higher than in individuals with lower mental ability (Kranzler & Jensen, 1989; Sheppard & Vernon, 2008). Furthermore, when RT is experimentally divided into a premotor time and a movement time, it is primarily premotor time rather than movement time which is associated with mental ability (Jensen, 1998, 2006).

With regard to a potential functional relationship between PRP and mental ability, these considerations might be important given that PRP is located at the premotor stage of information processing (Jentzsch et al., 2007). Because behavioral RT measures comprise both the time needed for premotor and motor processing the detection of a possible functional relationship between PRP and mental ability might be hampered by motor processes. Such a masking effect could account for the inconsistent findings of previous studies (Indermühle et al., 2011; Laguë-Beauvais et al., 2013; Lee & Chabris, 2013).

Proceeding from this line of argument, we extended our previous sample of 80 participants (Indermühle et al., 2011) to 190 participants to pinpoint the PRP effect at the stage of premotor information processing. For this purpose, we also analyzed LRP measures obtained in all subjects but not reported previously. For the behavioral data, we expected to confirm our earlier findings (Indermühle et al., 2011) obtained with the smaller subsample. The main goal of the present study, however, was to investigate mental ability-related differences in the PRP effect at the level of premotor processing by utilizing additional LRP measures rather than just behavioral RT measures. This might facilitate the identification of mental ability-related differences in the PRP effect since a potentially confounding influence of motor-related aspects of sensorimotor processing speed can be controlled for. If mental ability-related differences in the PRP effect indeed exist, they are expected to become evident much clearer for the S-LRP latencies than for rather global behavioral RT measures.

2. Method

2.1. Participants

We extended the sample of 80 participants from our previous report (Indermühle et al., 2011) to a total of 190 female undergraduate students ranging in age from 18 to 31 years (mean age ± standard deviation: 21.7 ± 2.6 years). Previous studies reported sex differences in evoked potentials (e.g., Cahill & Polich, 1992; Gurrera, O'Donnell, Nestor, Gainski, & McCarley, 2001), in choice reaction time (Adam et al., 1999; Dane & Erzurumluoglu, 2003; Der & Deary, 2006) as well as in the PRP effect (Laguë-Beauvais et al., 2013). To avoid that our results were biased by sex differences, the sample of participants was composed of women only. All participants included in the study were nonsmokers and reported normal hearing and normal or corrected-to-normal vision. For their participation they received course credit or the equivalent of USD 30.00. At the beginning of the first session, participants were informed about the study protocol and gave their written informed consent. The study was approved by the local ethics committee.

2.2. Assessment of psychometric intelligence

Intelligence was assessed by the short version of the Berlin Intelligence Structure (BIS) test (Jäger, Süß, & Beauducel, 1997). This test is based on the BIS model (Jäger, 1984) which proceeds from the assumption that each performance relies on operation-related abilities (Reasoning, Speed of information processing, Memory, and/or Creativity) and, concurrently, on content-related abilities (verbal, numerical, and/or figural abilities). The short version of the BIS test contains 15 subtests. Six subtests assess Reasoning (two verbal, two numerical, and two