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ADHD – From Basic Research to Therapy

Basic research in psychology usually means the study of the central nervous system and basic brain functions, typically by using animal or computational models. We should not expect it to have instant clinical relevance, as its aim is to understand more about basic mechanisms that, in time, may help us understand more about behaviour and how disorders come about. There seems to be a general opinion that the ultimate causes of behaviour should be looked for in the brain. However, the brain is an organ that *serves* behaviour; it is changed by the individual's interaction with the environment to the same extent as it contributes to those interactions. So, in order to understand how the brain works, we need to understand behaviour (Catania, 2000). Also, knowledge of basic *behavioural* processes may contribute to bridging the gap between knowledge about brain functions and how individuals function in their environment. Basic behavioural research on Attention-Deficit/Hyperactivity Disorder (ADHD; American Psychiatric Association, 1994) has been shown to be of direct clinical relevance.

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Reinforcement and the acquisition of behaviour

Within the lifetime of the individual organism, behaviour is selected by its consequences, much as organisms are selected over generations by evolutionary contingencies (Catania, 2000). The emission of behaviour provides the variations upon which operant selection operates. The most important mechanism in operant selection is reinforcement. A stimulus is acting as a reinforcer when the probability of repeating a response is increased by presenting the stimulus. Reinforcers are imperative during acquisition of behaviour, and they contribute to the maintenance of acquired behaviour.

Skills represent an important category of acquired behaviour. Skills involve units of behaviour and each high level unit (like typing or writing your signature) can be subdivided into lower-level units that involve smaller and more explicitly defined units, until at the lowest level, limbs or muscles are specified (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004). The higher levels are controlled by longer term consequences, and lower levels are controlled by short-term outcomes of individual movements. Thus, as behaviour becomes successively more skilled, smaller units are integrated into larger units, and the consequences for carrying out the sequence are postponed. A unit is defined functionally by what it brings about in terms of behaviour, not by the way specific neurones interact.

Reinforcement as a process operates within a limited time window from the occurrence of the behaviour to the perception of the consequences of this behaviour. Reinforcers' effect on behaviour can be depicted theoretically by the delay of reinforcement gradient (Figure 1). A reinforcer not only affects the response that produced it, it may also affect prior behaviour, although to a lesser degree. In addition, the relation between responses may be reinforced, as when a rhythm in button presses leads to the delivery of a reinforcer, the same rhythm tends to be repeated. With a normal delay gradient, lots of different time relations between responses may be reinforced. Additionally, it will be easy to establish the relation between a stimulus that signals that a certain behaviour will be reinforced, the actual behaviour, and the reinforcer.

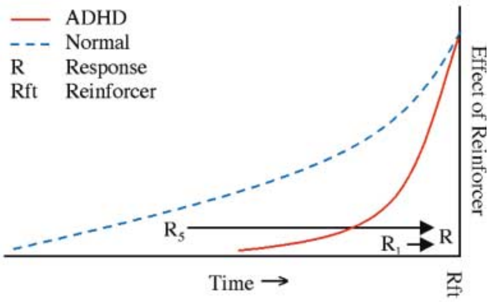

Figure 1. *Theoretical delay-of-reinforcement gradients*
The shorter and steeper delay gradient for ADHD (solid red line) implies that the relation between the response R_5 and R will not be reinforced, while this relation will be reinforced with a normal delay gradient (broken blue line). The relation between R_1 and R is close enough to be reinforced both when the delay gradient is short and when it is normal. A reinforcer will have almost the same effect on responses occurring immediately before reinforcer delivery with both a short and a long delay gradient, increasing the probability of repeating R with almost the same amount irrespective of the shape of the gradient. (Modified after (Sagvolden et al., 2005).

Reinforcement mechanisms in ADHD

ADHD is a disorder characterized by developmentally inappropriate levels of hyperactivity, impulsivity, and inattention. Impulsivity is increasingly seen as the main symptom, leading to inattention, hyperactivity, and increased variability of all behaviour.

ADHD may be a consequence of altered reinforcement mechanisms (Sagvolden, Johansen, Aase, & Russell, 2005). Altered reinforcement processes in ADHD can be described as a narrower time window than normal for associating behaviour with its consequences, or theoretically by a shorter and steeper delay gradient (Figure 1). This means that in ADHD, a reinforcer will affect rather few responses, only short time relations between responses will be selected, and a stimulus signalling what behaviour will be appropriate in a given situation will not work as discriminative stimulus if its onset is outside the reach of the delay gradient. In addition to resulting in increased variability in behaviour, reduced sustained attention, and hyperactivity, this implies that the establishment of behavioural units and the integration of units into longer sequences will be hampered. Thus, the ADHD behaviour will be characterized by short, disorganized, and undirected sequences of behaviour, or behaviour frequently characterized as impulsive.

Normally, impulsiveness will decrease with age (Panzer & Viljoen, 2005), as behaviour develops into increasingly larger units, behavioural sequences with more and more distal consequences. During practice, response time is normally reduced and responding is chunked into larger units that reinforcers will work on (Domenger & Schwarting, 2005). This process will be slowed in ADHD, may never catch up with normal development, and the behaviour may be characterized as immature.

Investigating learning and behavioural sequences in children with ADHD

Although self-control and the organization of behaviour over time have been described as the major problem of ADHD (Barkley, 1997), few studies have focused on the ordering and predictability of behaviour in ADHD. There are indications that development of functional units of behaviour, or performance of integrated behavioural sequences, is hampered in children with ADHD when the task gets increasingly complicated or demands higher-level processing (Sheppard, Bradshaw, Georgiou, Bradshaw, & Lee, 2000; Kalff et al., 2003; Siklos & Kerns, 2004).

Only one study has directly investigated acquisition of response sequences in the behaviour of children with and without ADHD (Aase & Sagvolden, 2005b). Here, the children completed a computerized task presented as a game with two squares on the screen, where mouse clicks on one of the squares resulted in a reinforcer. Reinforcers were cartoon pictures and small trinkets that were delivered after unpredictable time intervals contingent on responses. The spatial and temporal behavioural dimensions were analyzed by autocorrelating consecutive responses across five response lags. Acquired response sequences will then show up as predictable responding, where a substantial amount of variance was explained. In addition, the degree of learning was defined as the percentage of all responses that were correct (placed in the square associated with reinforcement).

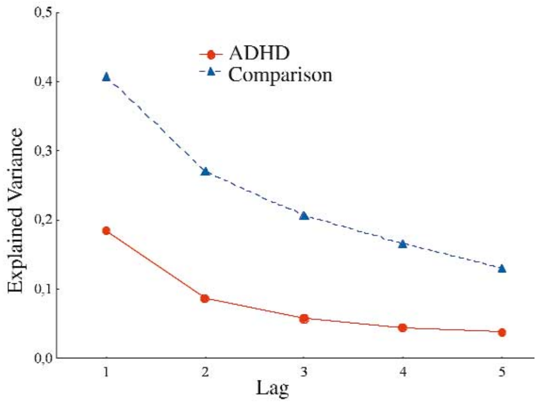

Figure 2. *Predictability of responding according to side of the screen*

Predictability of on which side of the screen consecutive responses were placed is depicted as mean explained variance (autocorrelations squared) from one response to the next (n+1, first lag) up to the sixth response (n+5, fifth lag). The graphs show means of the performance of the ADHD group and the comparison group across all segments (Aase et al., 2005b).

As predicted, the results showed that children with ADHD developed significantly shorter sequences of responses compared to children without ADHD on the spatial response dimensions. Figure 2 shows to what degree a response on one (of two) sides predicted the placement of the next response, the response after that one, and so on up to the sixth response in a sequence. The children without ADHD developed predictable response sequences of up to six responses in a row, while only two responses in a sequence could be predicted in children with ADHD. In addition, children with ADHD showed problems in learning the task; they performed marginally above chance level (Figure 3).

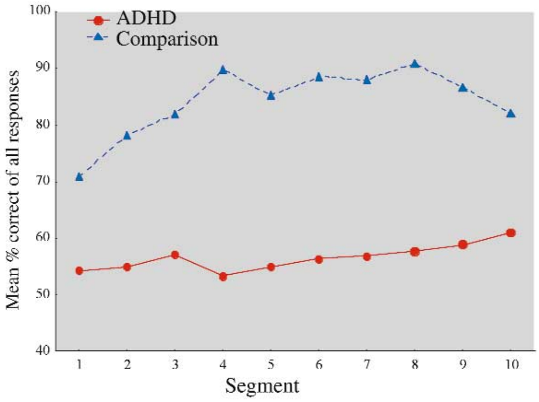

Figure 3. *Mean percent of all responses allocated to correct square*
Mean % correct responses for each group is depicted as means per segment (1 – 10) as a learning curve (Aase & Sagvolden, 2005a).

The findings suggest that children with ADHD have problems in learning long sequences of behaviour, particularly related to response location. Problems in learning long behavioural sequences may ultimately lead to deficient development of verbally governed (rule-governed) behaviour and self control. The study represents a new approach to analyzing the moment-to-moment dynamics of behaviour, and provides support for the theory that reinforcement processes are altered in ADHD (Sagvolden et al., 2005).

Implications for basic research

Acquisition of behavioural sequences may be related to habit learning, characterized by a transition from response-consequence associations that are flexible and sensitive to reinforcement devaluation, to stimulus-response associations that are less flexible and sensitive (e.g., Yin, Knowlton, & Balleine, 2004). These processes seem to involve separate brain areas (Lehericy et al., 2005). We think that our way of analyzing the dynamics of behaviour may be used during brain imaging in order to investigate which are the brain areas that show deviant activity in ADHD. The dynamic developmental theory of ADHD suggests that both the mesolimbic dopamine branch, involved in reinforcement and learning, and the nigrostriatal dopamine branch, involved in habit formation and motor control, may be dysfunctioning in ADHD (Sagvolden et al., 2005).

Clinical implications of hampered learning of behavioural sequences in ADHD

So – by analyzing behaviour on a very fine-grained level, we hope to find out which are the behavioural mechanisms that are the basis for a development that may include increasing problems and problem complexity in daily life. By a dynamic analysis of the details in behaviour, we hope to identify how a learning style characterized by acquisition of only very short units of behaviour may generalize into behavioural patterns described as disruptive behaviour, learning problems, and poor social skills.

The identification of micro-dynamic changes in the behaviour of children with ADHD may ultimately lead to the development of better assessment tools and early identification of dysfunctions. Better diagnostic tests may be used across age groups and in cultures completely different from Western ones. These improvements will in turn both provide opportunities for early intervention, and a basis for the development of improved medical and behavioural intervention programs.

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