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Fetal Learning: a Critical Review

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Learning is defined as a change in behaviour that occurs as a result of experience. It is clear that the fetus can learn by means of habituation, classical conditioning and exposure learning. These types of learning will be discussed in relation to learning in the womb and the memory of learned material after birth. Furthermore, the potential function of learning prenatally is explored in terms of its relevance for perinatal development. Copyright © 2010 John Wiley & Sons, Ltd.

Key words: fetus; learning; behaviour; memory

INTRODUCTION

Ultrasound has revealed the full term normal human fetus to have a sophisticated and integrated neurological system (Hata, Dai, & Marumo, 2009; Nijhuis, Prechtl, & Martin, 1982). But is the effect of prenatal exposure to stimuli retained and can the fetus learn? This question is not just of academic interest, but is relevant to the controversial issue of whether fetal neurodevelopment can be positively influenced and enhanced.

What is 'Learning'?

Learning can be defined in several ways, but in the context of psycho-neurological development it can be defined as a change in behaviour that occurs as a direct result of experience. Learning can vary in degree. It can be simple, for example, in the form of habituation and classical conditioning seen in many animal species. Or it can be more complex as represented by activities such as play and educational learning, seen only in relatively intelligent animals and humans. In addition, learning can be conscious or sub-conscious, the distinction between the two being dependent on whether the learning was actively undertaken by the individual.

The retention of a change in behaviour from experience (i.e. learning) is what we know as memory. It is clear that learning can be stimulated and a memory retained when any sense is stimulated (i.e. hearing, sight, smell, taste, touch and

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movement). However, in order to understand research into fetal learning, the following additional definitions of the more simple forms of learning are required.

Simple non-associative learning

Habituation is an example of non-associative learning in which there is a progressive diminution of behavioural response with repetition of a stimulus. There is an initial response to a stimulus and then the frequency and/or strength of the subsequent responses diminish with repeated stimulation. Many would argue that for the complete demonstration of habituation there needs to be a subsequent occurrence of *dishabituation*, namely the restoration of the original response to a stimulus after the discontinuation of the habituating stimulus. *Sensitization* in contrast, is an example of non-associative learning in which the progressive amplification of a response follows repeated administrations of a stimulus.

Associative learning

Operant conditioning is the use of consequences to modify the occurrence and form of behaviour. It is distinguished from Pavlovian conditioning in that operant conditioning deals with the modification of voluntary behavior. The typical approach for *classical conditioning* involves repeatedly pairing an unconditioned stimulus (which evokes a specific response) with another previously neutral stimulus (which does not normally evoke a response). Following conditioning, the response occurs both to the unconditioned stimulus and to the other, unrelated stimulus (or conditioned stimulus). Any learning occurring at a particular age or a particular life stage that is rapid and apparently independent of the consequences of behaviour is called *imprinting*. It was first used to describe situations in which an animal or person learns the characteristics of some stimulus, which is therefore said to be 'imprinted' onto the subject. Some describe this as 'exposure learning'.

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How is Fetal Learning Studied?

Research into fetal learning is difficult. It has been studied using habituation testing, classical conditioning and exposure learning (Hepper, 1997).

Studies using habituation have to a large degree relied on acoustic stimulation, though it is probably more correct to talk in terms of it being vibro-acoustic in nature since it is very difficult in this research to produce a pure acoustic stimulus without any vibratory elements (Bellieni *et al.*, 2005; Goldkrand & Litvack, 1991; Gonzalez-Gonzalez *et al.*, 2006; Groome, Gotlieb, Neely, & Waters, 1993;

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Groome, Singh, Burgard, Neely, & Deason, 1995; Groome, Watson, & Dykman, 1994; Hepper & Shahidullah, 1992; Johansson, Wedenberg, & Westin, 1992; Leader & Baillie, 1988; Leader, Baillie, Martin, & Vermeulen, 1982; Leader, Stevens, & Lumbers, 1988; Lecanuet, Granier-Deferre, & Busnel, 1988; Madison, Madison, & Adubato, 1986; Morokuma *et al.*, 2008; Nyman, Barr, & Westgren, 1992; Sandman *et al.*, 1999; Shalev, Benett, Megory, Wallace, & Zuckerman, 1989; Shalev, Weiner, & Serr, 1990; Smith, Davis, Rayburn, & Nelson, 1991; van Heteren, Boekkooi, Jongsma, & Nijhuis, 2000, 2001a; van Heteren, Boekkooi, Shiphorst, Jongsma, & Nijhuis, 2001b; Visser, Mulder, Wit, Mulder, & Prechtl, 1989). Also, these studies have largely focused on the human fetus rather than animal models. In contrast, virtually all the classical conditioning research into fetal learning has been in animal models using taste and/or smell as the stimulus (Arnold, Robinson, Spear, & Smotherman, 1993; Feijoo, 1981; Pavlov, 1906; Robinson, Arnold, Spear, & Smotherman, 1993; Smotherman, 1982; 2002a, 2002b; Smotherman & Robinson, 1985, 1991, 1993; Spelt, 1948; Varlinskaya, Petrov, Simonik, & Smotherman, 1997). Most of the work in this area, however, has used exposure learning as the model and has also used the widest variety of stimuli (vibro-acoustic, smell/taste and movement) (Abate, Pepino, Spear, & Molina, 2004; Chotro & Molina, 1992; Damstra-Wijmenga, 1991; DeCasper & Fifer, 1980; DeCasper & Spence, 1986; Fifer & Moon, 1989; Hepper, 1988, 1991; Hepper, Scott, & Shahidullah, 1993; James, Spencer, & Stepsis, 2002; Mennella, Jagnow, & Beauchamp, 2001; Moon & Fifer, 2000; Nelson, Brightwell, MacKenzie-Taylor, Burg, & Massari, 1988; Robinson, 2005; Shetler, 1989).

Evoked potentials methodology has been used extensively to study learning after birth (Lang & Kotchoubey, 2000). Whilst brain magnetic activity stimulated by both vibro-acoustic and light has been demonstrated in the fetus, these techniques have not been used to study fetal learning (Fulford *et al.*, 2003, 2004; Gross *et al.*, 1999; Sheridan, Matuz, Draganova, Eswaran, & Preissl, 2009). The majority of the studies of fetal learning have used some form of acoustic stimulation. However, there are wide methodological variations in the acoustic frequency and volume of the stimulus used in the exposure protocols and whether the sound source was applied directly to the maternal abdomen or in the environment. All these variables can influence the amount and quality of the sound reaching the fetus and thus its effects (Lecanuet *et al.*, 1998; Nyman *et al.*, 1991).

Can the Fetus Learn?

Habituation

Habituation (the ability of an organism to cease responding to a repeated stimulus) is a simple form of non-associative learning. One early demonstration of the phenomenon in the fetus was by Leader's group, who demonstrated habituation using electrocortical and electromyographic recordings in fetal sheep (Leader *et al.*, 1982).

Since then there have been many reports of habituation occurring in human fetuses. As gestation advances, the associated neurological maturation is reflected in faster habituation times (Groome *et al.*, 1993; Morokuma *et al.*, 2008; van Heteren *et al.*, 2001b). Such behavioural maturation has been reported to be significantly correlated with placental corticotropin-releasing hormone (CRH) concentrations (Morokuma *et al.*, 2008). It would appear that fetal behavioural state has no impact on habituation given that the two studies which explored this issue showed no significant difference in habituation speeds in quiescence versus activity (van Heteren *et al.*, 2001a; Shalev, Weiner, & Serr, 1990).

Fetal memory in the form of habituation has been shown to persist into neonatal life. Gonzalez-Gonzalez *et al.* (2006) reported a case-controlled study where

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newborns that were stimulated *in utero* habituated earlier than those who had not previously experienced the stimulation. There are studies that have shown a positive relationship between speed of habituation and developmental scores in infancy (Madison *et al.*, 1986).

Abnormal habituation has been reported in pathological fetuses. Slower or absent habituation has been demonstrated in 'high-risk', largely growth restricted, fetuses (Goldkrand & Litvack, 1991), those with hearing impairment (Johansson *et al.*, 1992) and fetuses with Down's syndrome (Hepper & Shahidullah, 1992). Similarly, fetal habituation pattern varies with maternal inspired oxygen concentration (Leader & Baillie, 1988). However, despite the clear evidence that fetal habituation is abnormal in pathological settings, there is little evidence that this evaluation has a role in fetal assessment in practice (van Heteren *et al.*, 2001b; Smith *et al.*, 1991).

Classical conditioning

There have been few studies of classical conditioning in the human fetus. The salivation of dogs in response to a buzzer in Pavlov's original experiment was the first description (Pavlov, 1906).

Most research into classical conditioning in fetuses has been undertaken in animal models and in particular by the sophisticated studies of Smotherman and colleagues (Arnold *et al.*, 1993; Robinson *et al.*, 1993; Smotherman, 1982; 2002a, 2002b; Smotherman & Robinson, 1985, 1991, 1993; Varlinskaya *et al.*, 1997). In one series of experiments, they demonstrated in D20 fetal rats that milk (unconditioned stimulus, US) infused into the fetal mouth produced characteristic facial wiping and mouthing movements. They were able to demonstrate after co-presentation with an artificial nipple (the conditioned stimulus, CS) that the same movements could eventually be produced with presentation of the CS alone (Arnold *et al.*, 1993; Smotherman, 2002a, 2002b; Varlinskaya *et al.*, 1997). This form of learning involved the mu and kappa opioid systems (Arnold *et al.*, 1993; Robinson *et al.*, 1993; Smotherman, 2002a; Smotherman & Robinson, 1993). It has further been shown that this form of classical conditioning could be demonstrated using different tastes, for example, with lemon as the US and sucrose as the CS (Smotherman & Robinson, 1991). Aversion behaviour could also be learnt in this way with lithium chloride as the US and mint as the CS taste/odour (Smotherman, 1982; Smotherman & Robinson, 1985).

There have been two reports of studies describing classical conditioning in the human fetus using vibroacoustic stimulation (Feijoo, 1981; Spelt, 1948). In the first, whilst classical conditioning was demonstrated, others have been unable to reproduce the response (Hepper, 1997). In the second, only one subject was used and no data were given (Spelt, 1948). More recently maternal relaxation (US) and music (CS) have been reported to produce fetal conditioning after more than 20 prenatal exposures. In the newborn, the CS induced a quiet awake state in conditioned fetuses (Feijoo, 1981). We chose not to use this approach in our studies because it is methodologically complex, has not been reliably confirmed as a method for the fetus, is non-physiological, and has been reported to occur in anencephalic fetuses (Hepper, 1997).

Exposure learning

There have been several studies, reviewed in Table 1, that have sought to address the question of whether the human fetus can learn using exposure methodology (Damstra-Wijmenga, 1991; DeCasper & Fifer, 1980; DeCasper &

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Table 1. Studies of exposure fetal learning

Author(s)	Year	Prospective study	Randomized study	Used 'Sham' stimulus	Used control group	Blinded observer	Demonstrated fetal response	Novel stimulus (no possibility of other exposure)	Neonatal learning impossible
DeCasper and Fifer	1980	Yes	No	No	Yes	Yes	No	No	No
DeCasper and Spence	1986	Yes	No	Yes	No	Yes	No	Yes	Yes
Hepper	1988	No	No	No	Yes	NK	No	No	No
Fifer and Moon	1989	Yes	No	No	Yes	Yes	No	Yes	No
Shetler	1989	NK	NK	NK	NK	NK	NK	NK	NK
Damstra-Wijmenga	1991	Yes	No	No	No	No	No	No	No
Hepper									
a. Neonate studies	1991	No	No	No	Yes	NK	No	No	No
b. Fetal studies		Yes	No	No	Yes	NK	Yes	No	N/A
Hepper *et al.*	1993	Yes	No	No	No	Yes	No	No	No
James *et al.*	2002	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

NK = Not known (no information provided).

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Spence, 1986; Fifer & Moon, 1989; Hepper, 1988, 1991; Hepper *et al.*, 1993; James *et al.*, 2002; Shetler, 1989). Many of these have given important insights into the effects of sound on the fetus, fetal hearing and learning.

DeCasper and colleagues (DeCasper & Fifer, 1980; DeCasper & Spence, 1986) studied fetal learning by recording the sucking response in newborns to recorded speech using a complex algorithm. In one study (DeCasper & Fifer, 1980), they measured the sucking response to 25 min of recorded speech in 10 newborns at 3 days of age. The speech was of the same text/script but each baby was exposed separately to his/her mother's voice and another female voice. The authors demonstrated a clear difference in the sucking response to the voice of the mother. There was no fetal exposure to the recording of the maternal voice and no demonstration of fetal learning before birth. The authors acknowledged the baby could have learnt the maternal voice after birth. To study fetal learning using a similar model, DeCasper and Spence (1986) carried out a prospective study of neonatal sucking responses in 16 babies whose mothers had read out loud selected passages twice daily over the last 6 weeks of pregnancy, instead of after birth. These babies demonstrated different sucking responses neonatally compared to two groups of control babies (one group prenatally exposed but to different readings than neonatally exposed and one group not prenatally exposed). Whilst the researchers did not attempt to demonstrate that that the fetus heard and responded to the mother's voice before birth, this study remains the most elegant and convincing evidence of fetal exposure learning of all the reported studies.

Hepper (1988) reported anecdotally the different behaviour of newborns whose mothers reported listening daily during pregnancy to the theme tune of a TV 'soap' programme compared to that of infants born to mothers who were not similarly 'addicted'. No experimental details were provided, but it is clear that the study was neither prospective nor randomized. It is also possible that, if the mothers had been 'addicted' to the TV programme during pregnancy, they would have watched the programme after birth and neonatal learning could have occurred. As discussed further below, Hepper's group subsequently used this model in more extensive and rigorous prospective studies (Hepper, 1991; Hepper *et al.*, 1993).

Fifer and Moon (1989), using a neonatal sucking model similar to that in DeCasper's studies (DeCasper & Fifer, 1980; DeCasper & Spence, 1986), demonstrated altered sucking behaviour in newborns when exposed to a recording of their mother's voice compared to another female voice. The authors admitted that this 'may' indicate fetal learning because they had not exposed the fetus to the recordings nor had they excluded the possibility of neonatal learning.

Shetler (1989), in a review of the impact of fetal music exposure, claimed from his own studies that fetal learning not only exists, but lasts for months and perhaps years. However, no methodological details of the research were provided by which the reader could judge the validity of these claims.

Damstra-Wijmenga (1991) also using neonatal behaviour to infer fetal learning performed a series of experiments that are difficult to interpret in terms of possible fetal exposure and learning. In a study of 28 newborns on the second day of life, a variety of sounds were played and their ability to 'pay attention' was noted. More than half (15) of the babies who could be observed whilst awake by two independent observers demonstrated 'attention' in response to hearing a recording of their mother's voice, but not when they heard another woman's voice or a lullaby that the mother had been required to play during late pregnancy. All the mothers had also been asked to play the recording of an alarming

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noise regularly in later pregnancy, but their newborns failed to be startled by such a noise either whilst awake or asleep. In contrast, a control group of newborns who not been so exposed *in utero* were startled when they heard the alarming sounds. The attention response to the maternal voice could have been due to neonatal rather than fetal learning. The failure of the prenatally exposed babies to respond to the music appears to be evidence against fetal learning. However, the music intensity on the maternal abdomen was only about 60–70 dB, and it is possible that this was not loud enough to be heard by the fetus. The fetal response to the prenatal stimulus (maternal voice, music or alarming sound) was not documented in these studies.

Finally, Hepper's group has contributed significantly to the fetal learning debate (Hepper, 1991; Hepper *et al*., 1993). They first reported a series of experiments using TV theme tunes as the exposure stimulus. The first experiment showed that newborns whose mothers claimed they had regularly watched a TV programme during pregnancy exhibited changes in heart rate, number of movements (reduction) and behavioural state 2–4 days after birth in comparison to a control group whose mothers said they did not watch the programme. The study protocol did not seek to document a fetal response or learning nor did it exclude the possibility of neonatal learning. A further series of experiments reported that this 'memory' was lost by 21 days. In a final more convincing series of experiments, they used similar methodology but exposed fetuses to a recording of the theme tune using a headphone applied to the maternal abdomen and recorded fetal behaviour using real-time ultrasound. Fetuses of mothers who regularly watched the programme behaved differently with increased fetal movements compared to those whose mothers did not. Unfortunately, no details of the methodology used to document fetal behaviour were given. Also no allowance appears to have been made for the influence of the pre-existing fetal behavioural state producing the findings by chance.

In the other studies Hepper *et al*. (1993) examined the ability of the fetus and newborn to distinguish the maternal voice. The newborn findings could have been the result of learning after birth. The fetal studies, conducted at 36 weeks, failed to show any differences in ultrasound recorded fetal movements when the baby's own mother's voice was played via a loudspeaker applied to the abdomen in comparison to a recording of another female voice. However, there were differences in fetal behaviour when the mother spoke 'naturally' compared to when the sound of her voice was played through the loudspeaker. Again, no allowance appears to have been made for the influence of the pre-existing fetal behavioural state producing the findings by chance.

In summary, several such studies of fetal learning using an exposure model have produced convincing evidence of fetal learning. However, they illustrate that this area of research is very difficult with many of the studies having methodological limitations as summarized in Table 1. These limitations include not being prospective, not being randomized, not using a novel stimulus (one that the fetus and newborn could never have heard before), not using a 'sham' or 'dummy' stimulus, not including a control group, not demonstrating both a fetal response to the stimulus and an evolution of that response with repeated exposure, and not excluding the possibility that neonatal exposure learning could have occurred. The study of James *et al*. (2002) was planned to overcome these problems. They undertook a prospective randomized controlled study and demonstrated that fetal exposure to a complex sound stimulus (music applied to maternal abdomen) results in the development of altered behaviour in the fetus, and that is carried forward in the form of altered behaviour in the newborn

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period compared to unexposed controls. The authors concluded that a simple form of fetal programming or learning had occurred.

All the human studies of exposure learning have used some form of vibro/acoustic stimulus. Other stimuli have been used to demonstrate fetal exposure learning, including taste/odour (ethanol, carrot flavour) (Abate *et al.*, 2004; Chotro & Molina, 1992; Moon & Fifer, 2000; Nelson *et al.*, 1988) and limb movement (Robinson, 2005). All these studies, however, were based on animal models.

What is the Relevance of Fetal Learning?

There is a large amount of evidence from habituation, classical conditioning and exposure learning research in animals and humans that the fetus can learn. In contrast, there is no sound evidence to show that providing extra auditory stimulation is of benefit to child development (Moon & Fifer, 2000). Theoretically, there could be risks to this approach though no adverse consequences have been proven. Possible functions of fetal memory are practice, recognition of and attachment to the mother (see DiPietro, 2009), promotion of breastfeeding, and language acquisition (Hepper, 1996). Future fetal learning research should focus on what are the possible benefits.

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