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Operant conditioning of the visual smooth pursuit in young infants

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Abstract

Smooth pursuit is a complex behaviour which is not considered as totally functional at birth. The lack of maturation of the visuo-motor systems is generally invoked to explain this phenomenon. However, if this oculomotor response is an operant behaviour, an alternate explanation may be found in the absence of previous confrontation with the environmental contingencies. A first group of young infants were placed in situations in which their oculomotor responses could produce an auditory stimulus. In such situations, young infants are able to improve their pursuit. Music was randomly delivered to a second group. No music was delivered to a third group. For the last two groups no augmentation of the proportion of slow movements was observed. Our main conclusion is that visual tracking has the properties of an operant behaviour and may be enhanced at birth. These results will be discussed within the frameworks of the behavioural discrepancy and of the maturationist hypotheses of the ocular motor control.

Keywords: Operant conditioning; Eye movements; Smooth pursuit; Young infants; Behavioural development; Behavioural selection

1. Introduction

Visual pursuit in adults is quite different from that of the young infant. In the adult, a target moving at a constant velocity elicits smooth pursuit eye movements which match target motion (Carpenter, 1988). Typically, the pursuit sequences are composed of slow movements interrupted by refixation saccades. In experimental conditions it is possible to observe large periods of pure smooth pursuit.

It has been concluded in some studies that the young infant's pursuit is exclusively composed of

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series of saccades until 8 weeks of age (Aslin, 1981; Johnson, 1990). The poor maturational state of both fovea and cortical structures involved in the oculomotor control of the pursuit behaviour is generally invoked to explain these results. Several authors (Kremenitzer et al., 1979; Roucoux et al., 1983; Charlier et al., 1993; Hainline, 1993; Buquet and Charlier, 1996; Von Hofsten and Rosander, 1996) show that, on the contrary, some episodes of smooth pursuit may be observed before 2 months of age. As it has been argued by Hainline (1993), differences in data may be due to the stimulus properties (mainly its size, velocity and nature of movements): when a large-sized target moving at a low velocity (less than 10°/s) is used, it is possible to elicit a tracking behaviour which is a mixture of slow movements and saccadic ones in the young child. Therefore, it appears that the young infant may be able to emit slow movements but differs from older infants and adults in the ability to control this behaviour.

The fact that saccadic and slow movements are under the control of independent oculomotor subsystems (Robinson, 1968) is favourable to the hypotheses of the independence of these behaviours. A saccadic movement is elicited by the appearance of a target in the peripheral retina. As the visual stimulus controls the emission of the response, this behaviour is an unconditioned response elicited by an unconditioned stimulus. This kind of behaviour is called respondent. Of course, this response may be implied in more complex behavioural structures during the infant development.

With the smooth pursuit response, the behavioural process is quite different. The presence of the retinal image of the target on the center of the retina is the consequence of the previous movement. Therefore, the consequence of a response at the time t commands the conditions of the maintenance of the response at the time $t+1$. In other words it would seem that the smooth pursuit is an operant behaviour, i.e. reinforced by its consequences. To be totally effective, an operant behaviour requires experiences in the environmental contingencies which will permit learning, that is to say, association between the behaviour and its consequences.

By cancelling the motion of the retinal image the smooth pursuit allows an optimization of the perception of the target. This optimization is only relevant if it is a part of behaviours involved in the adaptation of the organism to its environment. This is often true in natural situations. This is not true in most of the experiments on visual tracking in young infant. In such situations, the consequences of smooth pursuit is merely an activation of the center of the retina. As the value of such a reinforcer is usually very poor, one could not expect a great effect on the behaviour. In other words, it may be assumed that it is because the visual analysis, in these unnatural situations, is not important for the adaptation of the young infant, that his behaviour is not affected. This principle of reinforcement is referred to as behavioural discrepancy. The selection of a class of behaviours by its consequences requires a discrepancy between the operant response and the respondent behaviour, which is elicited by the reinforcing stimulus (Rescorla, 1968; Donahoe and Palmer, 1994). But if a visual stimulus only is presented to the center of the retina it will elicit a light oculomotor activity at the most minimal level. Thus in the classical experiments on visual pursuit the weakness of the discrepancy between the activity elicited by the target and the ongoing behaviour explains that the reinforcement effectiveness is poor. This could explain the low proportion of slow movements in the young infant's pursuit. On the other hand, in older infants and adults the visual pursuit has as a consequence behaviours involved in adaptation which ensure the behavioural discrepancy.

Consequently, one may postulate that improving the behavioural discrepancy will increase the reinforcement of the response, i.e. will raise the response rate. It is quite easy to raise behavioural discrepancy by adding a stimulus which act on a sensory system different from the visual system.

In the present experiment, the smooth movements produced an auditory stimulus. This procedure ensured behavioural discrepancy, since the oculomotor activity now had a consequence in the subject's environment which differed from the elicitor. As our purpose was to ascertain that the smooth pursuit was an operant behaviour, three

conditions were used. In the first one, the stimulus auditory was the consequence of the target behaviour (smooth pursuit): the auditory stimulus only appeared when the subject emitted a smooth pursuit response. In the second condition, the stimulus distribution is independent of the target behaviour: the appearance of the auditory stimulus did not depend on the emission of a smooth pursuit response but was randomly distributed. In the third one, no auditory stimulus at all was distributed.

With such a procedure, we expected that when the auditory stimulus was contingent upon the response, the response rate would increase more than when the auditory stimulus was distributed randomly. At the same time, we expected the response rate to be higher when there was an auditory stimulus than when this stimulus was not presented, assuming that the smooth pursuit behaviour would be reinforced, by chance, when the auditory stimulus was randomly presented.

2. Method

2.1. Subjects

This experiment was carried out in a maternity hospital. It involved 30 full-term normally delivered young infants aged from 1 to 7 days. None of the infants had any neurological dysfunction nor other particular pathologies, according to the first pediatric examination. We excluded infants of mothers who had used drugs. Between the experimental sessions, infants were with their mother. The procedure and topics of the experiment were explained to the parents and their informed consent was obtained. Some of them came into the experimental room during the recording sessions. We selected subjects in an alert inactive state. Data were recorded during 3–5 consecutive days at the rate of two sessions a day. Sessions last until subjects cried or fell asleep.

2.2. Stimulus

The visual stimulus was generated on a 20 inches video screen. The screen was viewed in binocular vision, at a distance of 30 cm and covered 60° of visual angle. The screen luminance was 5 cd/m^2. A target made of black and white grating of 0.4 cycles/degree, with a visual angle of 10°, was used (see Fig. 1). It moved back and forth, horizontally on a grey unstructured background at a velocity of 7.5°/s, with a speed reduction on the edges of the screen. The amplitude of the target's movement was 50°. The auditory stimulus was a 2-min loop of quiet music, with a level of 60 db.

2.3. Eye movement recording

Eye movements were measured with a pupil and corneal reflection system, sampling at the frequency of 30 Hz. This system used the relative position of the pupil and of the reflection of a near infrared light source over the cornea (Buquet and Charlier, 1994). As the light source was reflected through a hot mirror, there was little visual stimulation in the close visual field of the subject. It did not require any calibration and allowed a minimal setup time of the subject, as there was no contact with him (see Fig. 2).

A video camera recorded the pupil and the reflection of the light source over the cornea. Both were then identified by an image processing system. The data were recorded by a computer which calculated in real time the eye position and the instantaneous velocity gain, i.e. the ratio (instan-

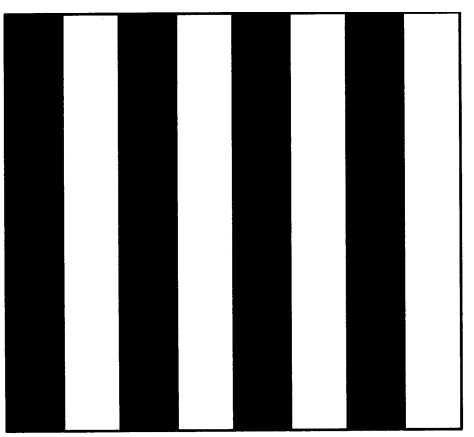

Fig. 1. Visual stimulus: grating of 0.4 cycles/degree.

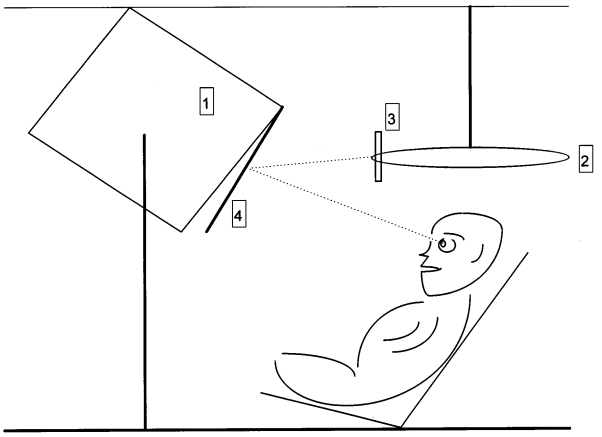

Fig. 2. Diagram of the experimental set-up: (1) cathode ray tube stimulator; (2) photo-oculograph; (3) infra-red light source; (4) hot mirror.

taneous velocity of the eye movement)/(instantaneous velocity of the target).

2.4. Procedure

Subjects were seated in a baby chair with an angle of 45°, in front of the video screen, in such a way that it was in the visual field of the subject when the head was straight (Buquet et al., 1992). After the setup, silence was made in the room and the subject was left free to move. When it was necessary, the experimenters modified the posture of the baby.

Data were recorded during trials of 38 s each. As the subject was free to look outside the screen (for example at his own body) trials were not scorable if there were not at least 300 recorded samples of gaze directed at the target. A sample was invalidated if, for example, the pupil was not detected.

At least two scorable trials without any reinforcement were first recorded for each subject as a baseline session. For the experimental sessions three groups of subjects were then constituted. In the first group no auditory stimulus was delivered at all (group No Music, NM, ten subjects). In the second group, music was delivered randomly during periods of 1–4 s separated by silences of 1–4 s (i.e. some music was delivered during the half of the total time of the trials) (group Aleatory Music, AM, 10 subjects).

In the third group (group Reinforced Slow Movements, RSM, 10 subjects) periods of slow pursuit were reinforced with a contingent auditory stimulus. A criterion was so as not to reinforce both periods of saccadic pursuit and movements away from the target: the mean of the instantaneous velocity gains computed for a temporal

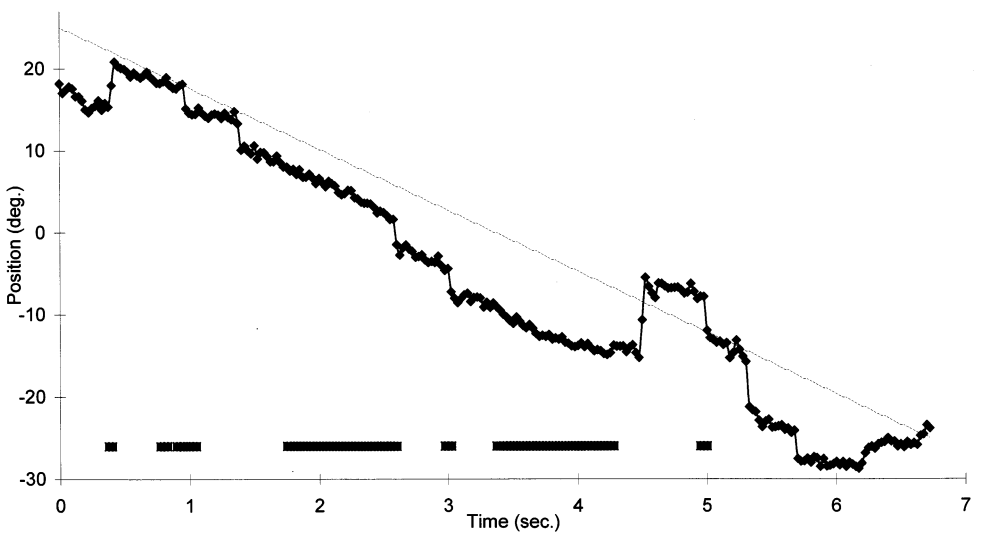

Fig. 3. Example of a tracking response (left eye). Thin line indicates the target's position as a function of time, dotted line indicates the position of the center of the retina. Full square at the bottom indicates the presence of the reinforcer.

window of 1 s. When this mean was higher than 0.1 we considered that the subject's visual pursuit was slow, and the system automatically delivered some music as long as the criterion was achieved. Therefore, only 1 s non-saccadic movements in the same direction as the target movement were reinforced (see Fig. 3). This relative low value criterion allowed sufficient quantity of reinforcer in order to act on behaviour considering the short duration of the experiment.

2.5. Data analysis

For each scorable trial the following ratio was computed: N_s/N_r, with N_s = number of slow movements with an instantaneous velocity gain higher than 0.1 and N_r = number of recorded samples. For each subject these proportions were used to calculate a mean score for the baseline session and one for the experimental sessions. In order to estimate the individual behavioural mod-

Table 1
Individual and groups means of proportion of slow movements for baseline and experimental trials[a]

	Baseline trials		Experimental trials		Change score
	n	*M* (S.D.)	*n*	*M* (S.D.)	
AM1	7	0.293 (0.167)	19	0.297 (0.089)	0.006
AM2	6	0.373 (0.078)	10	0.402 (0.108)	0.032
AM3	4	0.181 (0.058)	8	0.268 (0.086)	0.171
AM4	7	0.305 (0.059)	20	0.299 (0.088)	−0.009
AM5	5	0.180 (0.055)	7	0.290 (0.076)	0.207
AM6	6	0.256 (0.057)	17	0.280 (0.078)	0.039
AM7	4	0.316 (0.134)	29	0.349 (0.144)	0.042
AM8	6	0.314 (0.035)	13	0.211 (0.088)	−0.171
AM9	4	0.260 (0.039)	10	0.265 (0.149)	0.009
AM10	4	0.228 (0.080)	8	0.294 (0.054)	0.110
Mean (S.D.)		0.271 (0.062)		0.295 (0.051)	0.044 (0.105)
RSM1	4	0.266 (0.094)	14	0.256 (0.119)	−0.018
RSM2	2	0.118 (0.098)	6	0.290 (0.106)	0.389
RSM3	6	0.090 (0.044)	26	0.189 (0.081)	0.321
RSM4	4	0.374(0.041)	10	0.419 (0.057)	0.048
RSM5	7	0.119 (0.038)	17	0.126 (0.099)	0.025
RSM6	7	0.189 (0.105)	16	0.227 (0.092)	0.081
RSM7	6	0.094 (0.066)	17	0.164 (0.071)	0.242
RSM8	2	0.289 (0.180)	25	0.328 (0.167)	0.055
RSM9	4	0.306 (0.087)	13	0.346 (0.064)	0.053
RSM10	5	0.150 (0.041)	19	0.240 (0.070)	0.202
Mean (S.D.)		0.200 (0.102)		0.258 (0.089)	0.140 (0.139)
NM1	5	0.234 (0.124)	10	0.222 (0.068)	−0.024
NM2	6	0.204 (0.078)	20	0.128 (0.088)	−0.204
NM3	3	0.132 (0.027)	8	0.228 (0.106)	0.236
NM4	2	0.187 (0.000)	10	0.152 (0.052)	−0.090
NM5	6	0.192 (0.050)	15	0.175 (0.090)	−0.040
NM6	2	0.183 (0.090)	21	0.142 (0.064)	−0.111
NM7	6	0.234 (0.136)	17	0.197 (0.075)	−0.074
NM8	3	0.248 (0.048)	8	0.148 (0.063)	−0.224
NM9	5	0.264 (0.067)	16	0.191 (0.104)	−0.142
NM10	4	0.234 (0.183)	6	0.150 (0.096)	−0.194
Mean (S.D.)		0.211(0.039)		0.173 (0.035)	−0.087 (0.133)

[a] *n*, Number of trials; *M*, mean, S.D., standard deviation; Change score, Log (*M*experimental/*M*baseline).

ifications, an change score was computed using the log of the ratio of the experimental score compared to the baseline score for each subject. A logarithmical transformation was made to linearise these data.

A change score will be greater than zero means that the subject made more slow movements in the experimental sessions than in the baseline sessions. Conversely, a change score smaller than zero means that the subject made fewer slow movements during the experimental sessions than during the baseline one.

3. Results

3.1. Baseline scores

A non-parametrical analysis of variance test (H of Kruskal-Wallis) was used as the variances are not homogeneous (F_{max} (3,9) = 6.79, $P < 0.05$). There are no significant differences between the three groups for the baseline scores ($H(k = 3, n = 10) = 4.14$, $P > 0.05$) (see Table 1). In other words, the proportion of slow movements is not different for the NM, AM, or RSM group. Thus we may consider that the subjects from the three groups are equivalent to each other.

3.2. Experimental results

In order to analyze the subject's behavioural modification, each group was compared with the theoretical mean zero using Students t-test. The mean of the change scores for the subjects from the RSM group is significantly greater than zero ($t(9) = 3.18$, $P < 0.011$), indicating that the proportion of slow movements increased in the experimental session. There are no significant differences from zero for the AM group ($t(9) = 1.31$, NS). For the NM group the decrease approaches significance ($t(9) = -2.06$, $P < 0.069$) (see Fig. 4).

A one-way Anova revealed a significant effect of group ($F(2,27) = 8.07$, $P < 0.01$; the variances are homogeneous: F_{max} (3,9) = 1.75, $P > 0.05$). In order to test our two hypotheses, two orthogonal one-tailed contrasts were planned: AM versus RSM in order to test the effect of the reinforcement contingencies and NM versus AM and RSM to test the effect of an auditory stimulus on the proportion of slow movements. According to our hypotheses the change scores for the AM group ($M = 0.0436$) and for the RSM group ($M = 0.1398$) are significantly greater than the change scores for the NM group ($M = -0.0866$), $t(27) = 3.64$, $P < 0.001$ (one-tailed). Moreover, the change scores for the RSM group ($M = 0.1398$) are significantly greater than the change scores for the AM group ($M = 0.0436$), $t(27) = 1.70$, $P = 0.05$ (one-tailed).

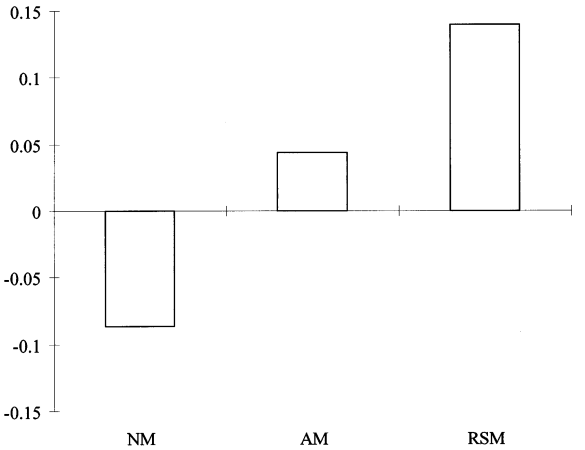

Fig. 4. Mean of the log-transformation of the ratio of the experimental score compared to the baseline score for each group.

4. Discussion

Our main goal was to ascertain that the response of smooth pursuit meets the criteria of an operant behaviour. The results show that enhancement of smooth pursuit by an auditory reinforcement as a consequence of the response is possible at birth. According to our hypotheses, only the subjects from the RSM group, i.e. who received an auditory stimulus as a consequence of slow movement in the direction of the movement of the target, increased their rate of slow movements with regard to the baseline sessions.

One may postulate that the auditory stimulus has an arousal effect which acts sufficiently on the global behaviour and perception of the subject to explain the increase in response rate. One of the effects of the presentation of a reinforcer is to arouse organisms (Killeen et al. 1978). However, as the proportion of slow movements of the subjects who received music in a random way increased less than the he proportion of slow movements of the subjects who received music as a consequence of their behaviour, our results may not be imputed to the arousal effects of the music. It is because the auditory stimulus is a consequence of the response that subjects from the RSM group increased their slow movements rate more than subjects from the group AM. Since some subjects have a high baseline score, one could suspected a ceiling effect on their experimental scores. In particular, the AM group exhibits the higher baseline mean score. Therefore, the lower experimental score of this group (compared to the RSM group) could be attributed to the fact that subjects are close to the maximum in the baseline score (and then without abilities to increase their slow movements proportions), rather than to the contingencies. It is not possible to evaluate the existence of such a ceiling effect. However, the three highest baseline scores in the RSM group (RSM4, RSM9, RSM8) can be paired with comparable scores from the AM group (AM2, AM4, AM1). In those three cases, the scores are higher in the RSM subjects (0.048, 0.053, 0.055, respectively) than in the AM subjects (0.044, −0.171, 0.009, respectively). Moreover, the highest baseline score in the RSM group is the highest of all subjects. Hence, a ceiling effect may not be invoked to explain lower scores in the AM group. The fact that randomly distributed music has the property of holding a proportion of slow movements does not contradict to our hypotheses: it is well known that, under a response-independent reinforcement contingency, the response rate is maintained at its baseline level (Herrnstein, 1966; Zeiler, 1968).

For the subjects who received only a visual stimulus, the rate of response slightly decreased. As stated earlier, because of the poor behavioural discrepancy, the reinforcement value of the visual target by itself was very poor. The continuous presentation of the visual stimulus reduces its effectiveness. This result may linked the habituation phenomenon. However habituation is decline in the strength of the response upon repeated presentation of a eliciting stimulus. In our case the visual smooth pursuit is not elicited by the visual stimulus since it is the issue of the behaviour. The repetition of the visual stimulus reduces the stimulus motivational value. So we think that the diminution of the reinforcement comes within a satiation process. This explains why effectiveness of the visual reinforcement decreases with regard to the baseline session. As we postulated, in experimental conditions in which the tracking of the target is not involved in the adaptation of the subject, the smooth pursuit decreased.

We conclude that adding an auditory stimulus ensured behavioural discrepancy and increased the reinforcement value of the auditory stimulus. As we are able to act on the occurrence of emission of slow movements by the manipulation of the reinforcement contingencies, the response of smooth pursuit may be considered as an operant behaviour.

In natural situation, smooth pursuit movements only begin to increase at around 2 months of age in young infants. We think that the conditions of the behavioural discrepancy arise during this period. From 2 months, premises of object manipulations and displacements of the subject allow visual pursuit to acquire adaptive consequences for young children. This period where slow movements of smooth pursuit are rare has been considered as an argument in favour of the maturation of a biological process. Thelen and Smith (1994) show that the maturationist explanation for behavioural development is seriously insufficient on both logical and empirical grounds. Their analysis of the locomotor development shows that organic components and context are equally causal. Thus they write: "While neural and anatomical structures are necessary for the expression of the behaviour, the sufficiency of a behavioural outcome is only completed with the task and context". (Thelen and Smith, 1994, p. 17). We think that the behavioural discrepancy is a necessary compo-

nent of both context and task in order for a new complex behaviour to emerge. This behavioural development may be seen as the result of the selection of activity patterns, with the reinforcer acting as the selection constraint. Such a description of the development is close to the neural group selection theory (Edelman, 1987). Sporns and Edelman (1993) consider that a somatic selection acts on a pre-existing movement repertoire, determined by the differential effects of the movements in the environment. By adopting this principle of behavioural selection, Friston et al. (1994) show that an auditory stimulus may acquire the ability of eliciting a response of discrimination, and, therefore, acquire a reinforcement value, as our experience indicates.

In adults, contrary to saccadic movements which do not necessarily involve a cortical control, smooth pursuit requires the cerebral cortex: according to Goldberg et al. (1992) the smooth pursuit pathway goes to the dordolateral pons from the primary visual cortex via the middle temporal area. For Johnson (1990, 1997), Aslin's observation of the lack of slow movements in the young child (Aslin, 1981) is explained by the absence of that cortical pathway at birth. However, slow movements have been observed before 2 months of age (Kremenitzer et al., 1979; Hainline, 1993; Roucoux et al., 1983). In view of these contradictory results, Hainline (1993) wondered if one could collect data allowing verification of Johnson's hypothesis about the maturational state of the cortical pathway. Since then, smooth pursuit in young infants has been confirmed (Charlier et al., 1993; Buquet and Charlier, 1996; Von Hofsten and Rosander, 1996). Moreover, we show that this behaviour could be controlled by its consequences. Such corpus of data should lead to a reconsideration of Johnson's hypothesis.

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