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OXYGEN CONSUMPTION AND NEONATAL SLEEP STATES

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SUMMARY

1. In thirty full-term infants in the first week of life, nursed in a constant volume, closed-circuit metabolism chamber in a neutral thermal environment (31·5–33·5 °C), measurements were made of oxygen consumption ($\dot{V}_{O_2}$) during periods of rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep.

2. The mean $\dot{V}_{O_2}$ during REM sleep was 5·97 ml. kg^{-1}. min^{-1}. In NREM sleep the mean $\dot{V}_{O_2}$ was 5·72 ml. kg^{-1}. min^{-1}. This difference was significant (paired *t* test $P < 0{\cdot}05$).

3. When the direction of sleep state change was taken into account the difference in $\dot{V}_{O_2}$ between the two states was much less when REM sleep preceded NREM than when the change was in the opposite direction. In nineteen infants in whom the change was from REM to NREM the difference in $\dot{V}_{O_2}$ (6·18 and 6·03 ml. kg^{-1}. min^{-1}) was not significant ($P > 0{\cdot}05$). The mean difference when the sleep state change was from NREM to REM was significant ($P < 0{\cdot}01$), the values being 5·54 and 5·81 ml. kg^{-1}. min^{-1} respectively.

4. In the NREM state, a gradual diminution of $\dot{V}_{O_2}$ with time was consistently found. This was not the case in REM sleep.

5. In twelve infants studied in a cool environment (29 ± 0·5 °C) $\dot{V}_{O_2}$ during REM sleep was 7·77, and during NREM sleep it was 6·58 ml. kg^{-1}. min^{-1}, ($P < 0{\cdot}001$). Thus even the maximum difference found in a neutral thermal environment of 6·6% was significantly increased to 14·9% ($P < 0{\cdot}01$) with mild thermal stress.

6. No consistent changes in $\dot{V}_{O_2}$ with time were found in either REM or NREM sleep in twelve infants studied in a cool environment, in contrast to the findings in thermal neutrality

INTRODUCTION

The first systematic measurements of oxygen consumption ($\dot{V}_{O_2}$) in the newborn infant were made by Benedict & Talbot (1915). Since then, studies have been made of metabolic rate in the new-born both in thermal neutrality and in a cool environment using a variety of techniques. In general these reports contained only sparse information on the behavioural state of the infants, who were usually described as resting or quiet.

Aserinsky & Kleitmann (1953) described two distinct sleep states in the adult, that associated with rapid eye movements (REM) and that with no rapid eye movements (NREM). Similar characteristics were reported in neonates by Kleitmann & Englemann (1953). Since then the effects of these states on cardiorespiratory phenomena (Bolton & Herman, 1974) and on exteroceptive responses in new-born infants (Prechtl, Vlach, Lenard & Kerr Grant, 1967) have been observed. There is, however, no information on the effects of REM and NREM on $\dot{V}_{O_2}$. The aim of the present study was to observe the effects of sleep states on $\dot{V}_{O_2}$, in a thermoneutral, and in a cool environment, the latter contributing an exteroceptive stimulus.

Brief reports of preliminary results of the $\dot{V}_{O_2}$ measurements made in a neutral thermal environment (Stothers & Warner, 1977*a*), and in a cool environment (Stothers & Warner, 1977*b*), have been presented to the Physiological Society.

METHODS

With the mother's informed consent, and often in her presence, forty-seven healthy new-born infants from the maternity wards of The London Hospital were studied. The study comprised four parts. Satisfactory records obtained from some infants enabled the data to be included in all four parts of the study, but the success rate varied, and in some cases it could only be included in one. In a neutral thermal environment thirty infants were measured for paired comparisons of $\dot{V}_{O_2}$ in both sleep states, and twenty-seven were measured during longer periods in a single state. In a cool environment, twelve were measured during contiguous REM and NREM states, and eighteen in a single state. There was no significant difference in mean ages (mean 3 days) or weights (mean 3·17 kg) between the four groups. The closed-circuit metabolic chamber described by Hill & Rahimtulla (1965), modified by Hey & Katz (1969), was used. In all cases the infants were measured lying prone and naked except for a small, plastic urine collection bag. At least 1 hr elapsed between the end of the last feed and the start of measurement. Minute-by-minute records of behavioural states, using the criteria of Prechtl & Beintema (1964), were made by the same experienced observer, continuously watching the infant for both body and eye movements. Traces during which more than one gross body movement occurred in any one minute were discarded, as were periods during which there was doubt as to the sleep state.

The environmental temperature (T_e) was calculated from the means of wall and air temperature using Gagge's (1940) formula,

$$T_e = 0{\cdot}6\ T_w + 0{\cdot}4\ T_a,$$

where T_w and T_a are the mean wall and air temperatures in °C respectively. In the thermoneutral series the chamber was set to the appropriate environmental temperature, calculated from Hey's (1969) data, ranging from 31·5 to 33·5 °C, depending on age and weight. In the case of the cool environment series the temperature was $29 \pm 0{\cdot}5$ °C. In the comparisons of $\dot{V}_{O_2}$ made during the different sleep states in any one infant, the environmental temperature did not vary by more than 0·2 °C.

In both of the paired series, the measurements were of contiguous periods of REM and NREM sleep lasting at least 8 min; 4 min elapsed from the end of measurement of one state to the beginning of measurement of the next, to allow for establishment of the sleep state, and for the chamber response time. In the steady states at least 10 min were required for inclusion.

Over each period minute-by-minute measurements from the traces provided the data for a Fortran programme written to calculate a mean $\dot{V}_{O_2}$, standard deviation and standard error in millilitres per kilogram per minute, corrected to standard temperature and pressure, dry.

RESULTS

Change in sleep state, neutral thermal environment

Analysis of the data from thirty contiguous REM and NREM sleep periods, irrespective of direction of change, showed a mean difference in $\dot{V}_{O_2}$ of 4·8 %, which was significant ($P < 0{\cdot}05$). In the case of nineteen infants in whom a period of REM sleep preceded one of NREM the difference of 2·7 % was not significant ($P > 0{\cdot}05$). The 6·6 % rise in $\dot{V}_{O_2}$ during REM sleep observed when the change was in the opposite direction was significant ($P < 0{\cdot}01$) (Table 1).

Steady state, neutral thermal environment

Linear regression of $\dot{V}_{O_2}$ against time was calculated during more prolonged periods of REM and NREM sleep. In REM sleep the signs of the slopes were variable, seven infants showed a tendency to increase and eleven to decrease with time, the range of values being from $+0{\cdot}07$ to $-0{\cdot}40$ ml. kg^{-1}.min^{-2}. During NREM sleep none of the eighteen infants had positive values, the range was from 0·00 to $-0{\cdot}36$ (two-tailed t test, $P < 0{\cdot}01$).

Change in sleep state, cool environment

The mean $\dot{V}_{O_2}$ values of the twelve infants studied in a cool environment was 14·9% higher in REM sleep than when in NREM sleep ($P < 0{\cdot}01$). Eight were measured when the change was from REM to NREM, and eight in the reverse direction. The results were not significantly different from the values given above, when direction was disregarded (Table 2).

TABLE 1. Neutral environment

Direction of sleep state change	Number of infants	Oxygen consumption (ml. kg^{-1}.min^{-1} ± S.D.) REM	NREM	Significance (related t test)
NREM ⇌ REM	30	5·97 ± 0·86	5·72 ± 0·70	$P < 0{\cdot}05$
REM → NREM	19*	6·18 ± 0·97	6·03 ± 0·64	$P > 0{\cdot}05$
NREM → REM	22*	5·81 ± 0·62	5·45 ± 0·61	$P < 0{\cdot}01$

* Eleven studied in both directions.

TABLE 2. Cool environment

Direction of sleep state change	Number of infants	Oxygen consumption (ml. kg^{-1}.min^{-1} ± S.D.) REM	NREM	Significance (related t test)
NREM ⇌ REM	12	7·66 ± 1·00	6·58 ± 1·26	$P < 0{\cdot}001$
REM → NREM	8*	7·51 ± 1·01	6·50 ± 1·35	$P < 0{\cdot}01$
NREM → REM	8*	7·70 ± 1·28	6·62 ± 1·04	$P < 0{\cdot}02$

* Four studied in both directions.

Steady state, cool environment

Twelve infants were studied in more prolonged periods in both sleep states in a cool environment. In each state six showed a tendency to increase their $\dot{V}_{O_2}$ with time, and six to decrease (range 0·28 to $-0{\cdot}43$ ml. kg^{-1}.min^{-2}).

DISCUSSION

The results of the first two groups of infants studied, those nursed in a neutral thermal environment, are diagrammatically represented in Fig. 1. The differences in $\dot{V}_{O_2}$ due to direction of change only became apparent because the periods of study were contiguous and the order of sleep state recorded. This effect may explain the lack of difference in $\dot{V}_{O_2}$ with varying states of 'vigilance', which corresponded to REM and NREM sleep, in the infants studied by Stabell, Junge & Fenner (1977). In spite of individual variation, however, which presumably prevented statistically significant differences being reached, it is interesting to note that their figures suggest a mean increase in $\dot{V}_{O_2}$ of approximately 10 % in REM sleep. Similar increases have been reported in premature infants by Scopes & Ahmed (1966), and in adults by Brebbia & Altschuler (1965).

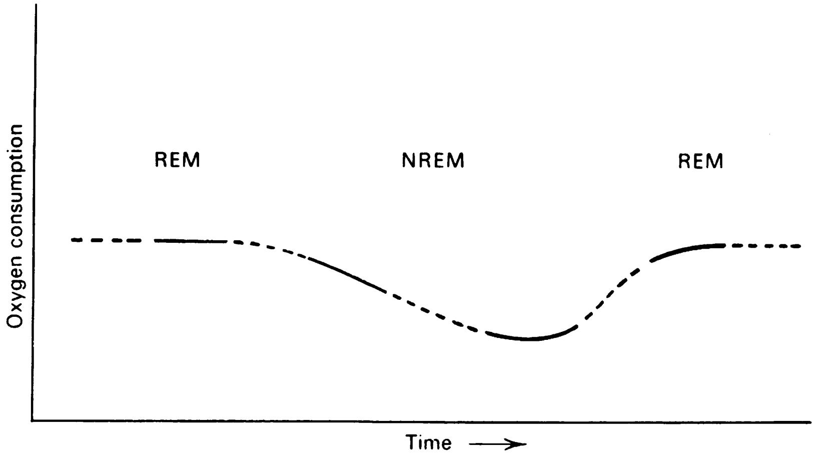

Fig. 1. Diagrammatic representation of $\dot{V}_{O_2}$ with time in a thermoneutral environment. The continuous lines show the periods measured, the interrupted ones the intervals between measurement.

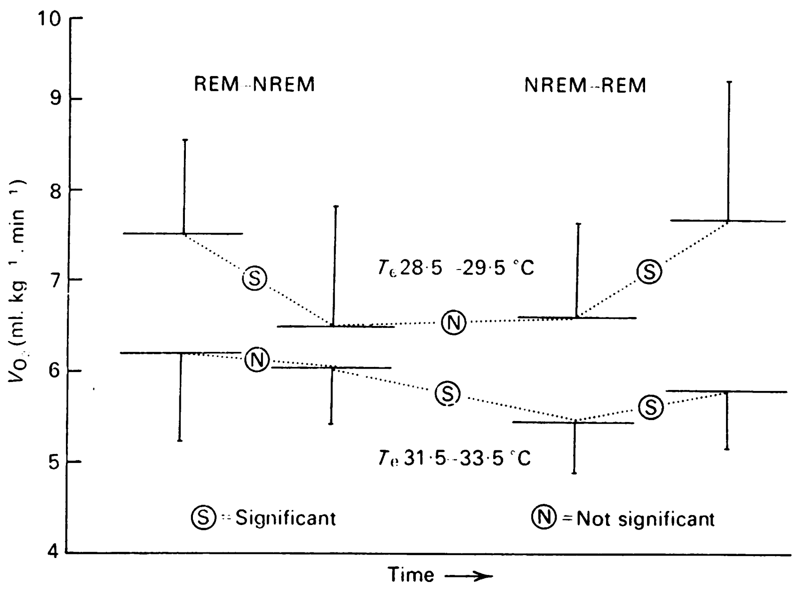

Fig. 2. Mean $\dot{V}_{O_2}$ values ($\pm$ S.D.) in the two sleep states, and the direction of change in both thermoneutral and cool environments.

A review of the mean $\dot{V}_{O_2}$ found by earlier workers in the neonatal field shows our values to be lower than most (Benedict & Tablot, 1915; Brück, 1961; Hill & Rahimtulla, 1965; Hey, 1969; Sulyok, Jéquier & Prod'hom, 1973). Our strict criteria regarding movement, that is, to exclude traces of periods during which more than one body movement occurred in any one minute, almost certainly explains this, also the infants in our series were measured in the prone position whereas most other workers have studied them supine.

Diminished response to exteroceptive stimuli during NREM sleep in the infant was reported by Prechtl *et al.* (1967). In that investigation stimulation over the distal part of the tibia resulting in dorsiflexion of the foot was used. In NREM (termed by them state 1) the motor response was found to be weak or absent, whereas in REM (state 2), the motor response was more frequent and stronger. It is therefore not surprising that in a cool environment the difference in $\dot{V}_{O_2}$ between REM and NREM sleep was even greater than when measured in thermal neutrality (Fig. 2).

An observation made during the course of the study was the skin pallor frequently associated with NREM sleep. It is interesting to speculate that this phenomenon, almost certainly due to reduced skin blood flow, provides some degree of protection against heat loss in situations involving decreased $\dot{V}_{O_2}$ with consequent diminished heat production.

Our findings suggest that when short, comparative measurements are being made in the new-born in neutral thermal conditions, account must be taken not only of the sleep state, but also of the position of the study-period within the total sleep cycle. In lowered environmental temperatures the sleep state is of even greater importance, although the position within the cycle would appear to be of little importance.

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