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ADDITIONAL CONFIRMATION FOR THE EFFECT OF ENVIRONMENTAL LIGHT INTENSITY ON THE SEASONALITY OF HUMAN CONCEPTIONS

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Summary. Causality for the seasonality of human births, which affects populations wordwide, has been a profound mystery for nearly two centuries. Most explanations for seasonality fail because of inconsistent global application. In two previous studies, Cummings (2002, 2003) hypothesized that human reproduction has been responsive to changes in both seasonal environmental light intensity (surface luminosity) and photoperiod. Except at higher latitudes, photoperiod is of secondary importance to that of environmental light intensity. Because of a lack of data, the presence or lack of cloud cover is used as a general proxy for environmental light intensity. These studies show a positive correlation between conceptual seasonality and cloud cover on a worldwide basis, and propose that there is a delay between exposure to increased light and the onset of conceptions. This delay is three months at higher latitudes and one to two months for lower latitudes. Both studies suggest that an excellent means of hypothesis confirmation would be to provide one or more examples of how a seasonal change in cloud cover might alter the number of conceptions in subsequent months. The present study tests this hypothesis. The percentage of possible sunshine and averaged sunshine hours are used to investigate their influence on seasonality of births in Germany and the Netherlands. The evidence shows that a seasonal change in environmental light intensity preceded a change in the peak months for conceptions in Germany and the Netherlands. Although secondary influences are possible, the primary reason for this transition in peak conceptual months seems to be related to the seasonal changes in environmental light intensity for both countries. Although this transitional relationship was predicted in Cummings (2002, 2003), further research is required, especially with regard to more precise measurements of environmental light intensity and its physiological effect on the human endocrine system.

Introduction

The primary purpose of this paper is to investigate whether the seasonal changes in conceptions (the months in which most conceptions occur) in the 1970s and 1980s in

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Germany and the Netherlands followed a seasonal change in regional environmental light intensity (ELI). Environmental light intensity causality for such a transition was predicted in Cummings (2002, 2003). In the present paper, a meteorological variable – the percentage of possible sunshine – is used as a general indication of ELI for Germany. For the Netherlands, however, a second variable – averaged monthly sunshine hours – is used.

Since this paper is primarily focused on hypothesis testing, a detailed review of the previous explanations given for human birth seasonality, or seasonality, is not undertaken. Generally, seasonality explanations follow a path of either sociological or biological causality (see Roenneberg & Aschoff, 1990; Lam & Miron, 1991, 1994).

The present paper favours a singular approach involving light as the cause of seasonality because of its more parsimonious basis. Sociological explanations, and even some biological ones, tend to be more cumbersome and sometimes involve multiple determinants. On the other hand, for more than a century a wealth of scientific evidence has emerged to verify the importance of light to the reproductive process. As a fundamental stimulus, light enters the organism via the optical–pineal axis to influence the pineal's secretion of melatonin. In turn, melatonin modulates the reproductive cycle. In more recent years, some researchers have found that increased diurnal light may affect melatonin production as well as shift female circadian rhythms (Hashimoto, *et al.*, 1997; Park & Tokura, 1999).

In deference to the fundamental role that light plays in the reproductive process, as well as being a primary zeitgeber for our biological rhythms, light should be considered as the first variable likely to influence the seasonality of human births. Adherence to the principle of Occam's Razor does not imply, of course, that light is responsible for seasonality. Rather, it merely suggests that we should first concentrate on the light/reproductive relationship for causality before advancing to more complicated arguments. Presently, ELI and photoperiod (PP) cannot be eliminated as possible causes for human birth seasonality, and the more complex explanations should be held in abeyance. If light can be eliminated as a likely cause for seasonality, then these explanations should be given greater credence. For more detailed information regarding the relationship between ELI and conceptual seasonality, see Cummings (2002, 2003); for a review of German seasonality see Lerchl *et al.* (1993) and for seasonality in the Netherlands see Haandrikman (2004).

To briefly review the hypothesis being tested, it has been proposed (Cummings, 2002, 2003) that the primary basis for human conceptual seasonality derives from our physiological sensitivity to slight variations of light, particularly to seasonal changes in ELI (surface luminosity or brightness). Unfortunately, there are no known recorded measurements of ELI, at least from a historical perspective. Consequently, it has been necessary to substitute a proxy for ELI, namely cloud cover. In these studies, it seemed reasonable that a seasonal period of bright sunny days would also be a seasonal period of increased ELI. In this event, increased ELI may evoke a positive reproductive response from the human endocrine system with an apparent increase in conceptions. The possible effect of increased light on fertility, however, did not seem immediate. There is a delay between exposure to increased ELI and the time at which the increased numbers of conceptions become evident. Given the normal human menstrual cycle at 28 days, a lag between increased light exposure and conception is not unreasonable. This delay, or endocrine response period (ERP), may be 1–3 months before increased conceptions become evident. At higher latitudes, the ERP seems to be three months. At lower latitudes, the ERP may be shorter, normally 1–2 months. Generally, the northern tier of USA states may be considered the dividing line between lower and higher latitudes.

It has further been suggested that in moving poleward from the equator, ELI loses strength and PP becomes the dominant variable to influence seasonality. Because of the annual consistency of PP, we should expect to find greater year-to-year stability for seasonality patterns at the higher latitudes. This viewpoint seems to be substantiated by the nearly consistent seasonality patterns found for Canada and the Scandinavian countries (Lam & Miron, 1991).

While a male contribution to seasonality may be more immediate, the most obvious and meaningful effect may result from the female reproductive cycle. The ubiquitous influence of increased seasonal ELI may alter and entrain the menstrual cycles for large numbers of exposed women. Essentially, increased menstrual synchronization in a broad population might produce an apparent increase in conceptions and an ultimate increase in births nine months later. Depending on latitude, up to three months may lapse before increased conceptions become statistically apparent. In Germany and the Netherlands, as well as at other higher latitude locations, the ERP is approximately three months.

Most importantly, in Cummings (2002) it was found that during 1926–1945, a seasonal transition in cloud cover occurred over much of the United States. It was thought that if increased conceptions result from increased ELI, then a seasonal trend of changing ELI may have produced the ‘the gradual diminution in the February peak and accentuated the September peak,’ as noted by Rosenberg (1966). In further consideration, transitional seasonal cloud cover seemed to support this premise. In this case, increased ELI (reduced cloud amount) during Sepember–October–November may have promoted an increase in the number of births the following July–August–September. There was a net loss of approximately 1800 clear days during this time-frame. In Cummings (2002, 2003), it was predicted that this identical relationship should exist elsewhere:

> If the present hypothesis is correct, this phenomenon should be evident in locations besides the US. In these areas, long-term variation in seasonality should be associated with changes in cloud cover. Normally, conceptions may be predicted to decline from previous periods of increasing cloud cover and to increase because of previous periods of decreasing cloud cover.

This brings us to a change in European birth seasonality. During the past forty years or so, the peak months for births have changed for some European locations. In their study of West German birth rates, Lerchl *et al.* (1993) found a shift in birth seasonality from a normal springtime peak in March to a peak in September. This transition in births started in the middle 1970s and was strongly evident by the middle 1980s. The same relationship has been noted in the Netherlands where seasonality also assumed the American pattern (Haandrikman, 2004). Again, is it possible that German and Netherlands ELI also changed at this time so that spring months became cloudier and the fall months sunnier? Such was Cummings’ original prediction. Consequently, the primary purpose of the present paper is to investigate whether the change in birth seasonality was preceded by a similar change in ELI for Germany and the Netherlands.

Table 1. Averaged quarterly percentage of possible sunshine amounts (Hannover, Germany, 1969–89)

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1969	44	57	89	76	98	67	99	104	102	99	95	88
1970	116	76	56	87	51	83	140	85	111	80	53	123
1971	63	122	58	91	87	99	68	131	117	89	159	87
Average			76			82			106			97
1972	228	101	64	113	75	77	93	89	102	75	148	65
1973	133	61	71	97	64	91	117	98	128	85	89	136
1974	78	67	96	97	114	77	84	74	106	86	54	62
Average			100			89			99			89
1975	79	118	147	95	58	85	84	124	152	102	93	73
1976	146	73	66	105	106	90	130	129	124	64	63	76
1977	32	62	89	85	70	108	67	85	72	87	111	62
Average			90			89			107			81
1978	57	72	94	62	87	77	97	89	82	49	71	112
1979	53	47	49	70	103	86	89	75	94	96	134	113
1980	80	80	87	65	82	117	81	66	93	103	77	76
Average			69			83			85			92
1981	19	102	82	54	92	99	66	66	90	90	81	89
1982	88	142	141	114	101	105	96	132	112	112	74	83
1983	206	55	97	64	69	50	111	137	138	86	101	154
Average			104			83			105			97
1984	61	103	102	111	107	53	63	70	114	65	101	167
1985	82	83	153	52	74	86	86	106	115	88	90	82
1986	135	102	175	82	67	118	126	111	103	81	115	190
Average			111			83			99			109
1987	88	109	110	118	83	73	70	109	78	84	116	242
1988	103	107	78	60	110	124	65	92	119	72	75	100
1989	115	167	148	103	65	146	131	95	116	87	101	237
Average			114			98			97			124

Methods

Sunshine data

Data for the percentage of possible sunshine units shown in Table 1 are available from monthly meteorological reports published by the World Meteorological Organization (WMO) and the National Oceanic and Atmospheric Administration (NOAA). The earliest recorded entry for these data appears in January 1969. Starting in January 1987, sunshine data were expanded to include both total sunshine in hours and the percentage of long-term average. These data are accessible on the worldwide web (see acknowledgments).

Percentage of possible sunshine

Rather than cloud cover values, the present study considers yet another meteorological variable as an indication of seasonal brightness – the percentage of possible sunshine. It is important to note that this variable does not measure the strength of surface luminosity (ELI), only its duration. Sunshine duration may be defined as the length of time a visible shadow is cast by an object exposed to sunshine. Sunshine measurements, unlike cloud cover values, may better account for seasonal photoperiodic differences and the possible presence of airborne particulate matter, i.e. smoke, dust or haze. The percentage of possible sunshine readings shown in Table 1 and the figures are calculated from thirty-year averages for each particular month. An example might clarify as to how to understand the percentage of possible sunshine values. If the long-term average for July is 10,000 minutes and if 12,900 minutes were observed in July 1976, then the percentage of average sunshine for July 1976 will be '129% of possible'.

One of the better known sunshine recorders is the Campbell-Stokes device, which was standardized by the World Meteorological Organization (WMO) in 1961. This simple, but effective device employs a glass sphere to focus the sun's rays onto a card mounted within a sphere. Different shaped cards are used for different seasons. Cards are photo-sensitive to sunlight and produce a char from the sun's rays. As the earth rotates, the position of the char moves across the card. If clouds obscure the sun, the trace is interrupted and no char is recorded. At the end of the day, the length of the char, minus gaps, is proportional to the daily duration of possible sunshine.

While the duration of this variable (the percentage of possible sunshine) is recorded as temporal percentages, it is entirely correct to assume that these sunshine periods are also indicative of stronger ELI. Essentially, increased periods of possible sunshine are also increased periods of ELI. While the precise strength of ELI may not be known, it can safely be assumed that ELI is greater with sunshine than without it. This concept may be expanded to a broader application than just daily readings. For example, if sunshine units are averaged for the period March, April and May during the three-year period 1969–1971, and if similar monthly readings averaged for 1972–1974 are higher, then it may reasonably be concluded that ELI has increased during these subsequent years, at least for the same three-month period.

Percentage of possible sunshine values for Hannover, Germany

These data were collected for Hannover, Germany, for the period 1969–1989. Hannover was selected because of its more or less central location in western Germany and because this regional area is densely populated. According to data received from Peter Bissolli and Clemens Barfus in 2005 (Deutscher Wetterdienst), seasonal cloud cover patterns over western Germany appear to be generally consistent. It would seem that any seasonal pattern found for sunshine duration in Hannover would be applicable for the non-mountainous areas of Germany as well. Possible differences, if any, might relate to the degree of sunshine rather than to a marked deviance from an overall pattern.

Table 1 displays monthly percentage of possible sunshine data collected for Hannover, Germany, from 1969 to 1989. Data are arranged quarterly. The first quarter is December–January–February (Dec–Jan–Feb). The second quarter is March–April–May (Mar–Apr–May). The third quarter is June–July–August (Jun–Jul–Aug). The fourth quarter is September–October–November (Sep–Oct–Nov). This configuration agrees with the previous methodology constructed for US cloud cover transition (Cummings, 2002). The monthly values shown in Table 1 are raw data that have not been altered statistically. The only alterations have been to develop average values for each quarter in each three-year period. Averaged values are compared vertically. For example, the quarter Dec–Jan–Feb (1969–71) is compared with the same quarter Dec–Jan–Feb (1972–74) and so on. Averaged amounts for the same quarter are compared in Figs 1–4.

Annualized monthly sunshine hours for the Netherlands

Another means to determine seasonal differences in ELI is to compare monthly hours (averaged) from two different long-range periods for the same location. If seasonal differences in ELI exist, these differences would be evident in long-range data. The WMO/NOAA report being used, however, does not reflect long-range averages. For the present purposes, long-range averages are derived from the monthly data shown by dividing the actual monthly hours by the percentage of long-range average. For the first period, data are based on the 1988 report for the Netherlands. Long-range averages in this report are calculated for the period 1931–60. Long-range averages in the second report come from 2005 data. Data in the 2005 report are based on monthly averages from 1961–90. In summary, the averaged monthly hours of sunshine in the Netherlands during the period 1931–60 are simply being compared with the averaged monthly hours of sunshine during the period 1961–90. These results are shown in Table 2.

Results

Germany

The averaged results from Table 1 are shown in Figs 1–4. There are no obvious patterns of sunshine change for the two quarters Dec–Jan–Feb (Fig. 1) and Jun–Jul–Aug (Fig. 3). More definitive patterns, however, may be seen for the two quarters Mar–Apr–May (Fig. 2) and Sep–Oct–Nov (Fig. 4). These patterns began to change in 1975–77 for both quarters. For Mar–Apr–May (Fig. 2), there was a downward trend in ELI, starting in 1975 and running through 1986 with lower averaged values. In Fig. 2, even during 1986–89 when sunshine units increased, they are still below the long-term average. For Sep–Oct–Nov (Fig. 4), there was an increase in ELI, starting in 1975 and continuing through 1989 with higher averaged values. Essentially, the quarter of Mar–Apr–May (Fig. 2) became cloudier while the

Table 2. Average monthly hours of sunshine in two long-range periods (Debilt, Netherlands)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1961–90	46·1	73·1	106·4	151·6	197·3	192·0	187·9	185·0	133·5	102·9	55·0	42·9	1473·7
1931–60	58·1	68·2	127·2	162·5	214·4	214·5	198·4	187·3	146·1	102·8	49·2	40·0	1568·7
Change	− 12·0	4·9	− 20·8	− 10·9	− 17·1	− 22·5	− 10·5	− 2·3	− 12·6	0·1	5·8	2·9	− 95·0

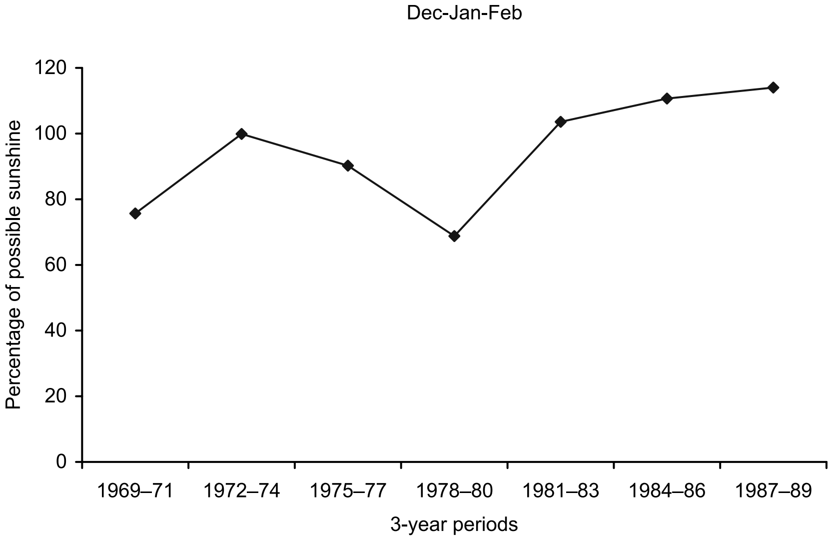

Fig. 1. Averaged quarterly sunshine percentage (Dec–Jan–Feb) for Hannover, Germany.

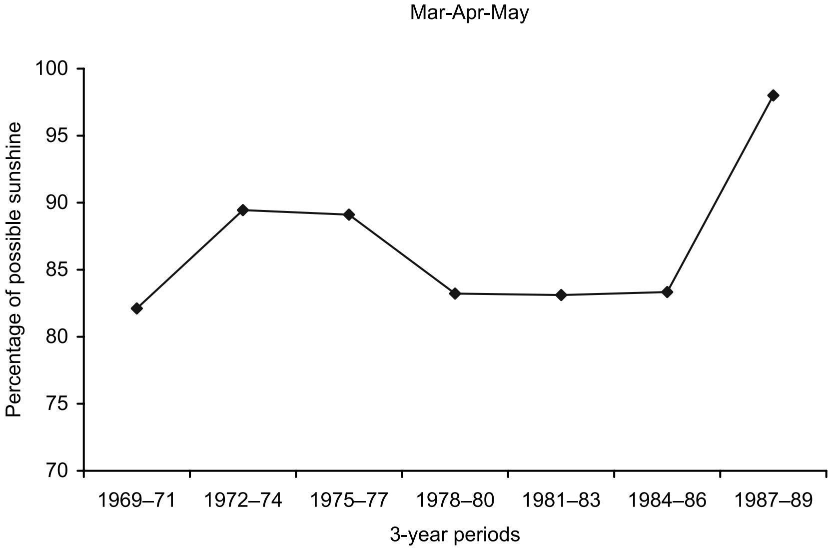

Fig. 2. Averaged quarterly sunshine percentage (Mar–Apr–May) for Hannover, Germany.

quarter of Sep–Oct–Nov (Fig. 4) became sunnier. Unquestionably, there was a shift in German seasonal ELI during this time.

Lerchl *et al.* (1993) report the transitional change in seasonal German birth rates from 1951 to 1990 (Fig. 5). According to these authors, however, it was not until the

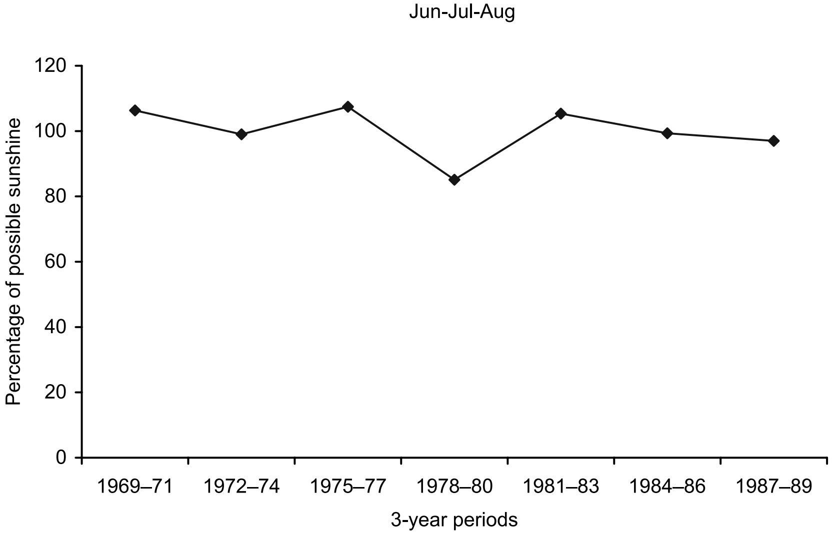

Fig. 3. Averaged quarterly sunshine percentage (Jun–Jul–Aug) for Hannover, Germany.

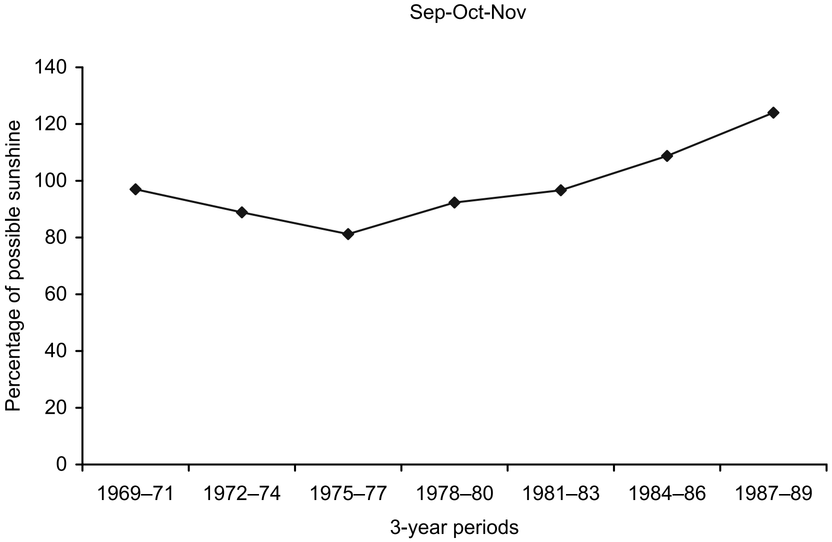

Fig. 4. Averaged quarterly sunshine percentage (Sep–Oct–Nov) for Hannover, Germany.

middle 1970s that March began to be slowly displaced by September as the peak month for German births. By the middle 1980s, the transition appears to be complete with September being the peak month for births. From Figs 1–4, it is apparent that there was also a concurrent change in ELI at this time: it was being reduced during Mar–Apr–May (Fig. 2), while it was being increased in Sep-Oct-Nov (Fig. 4).

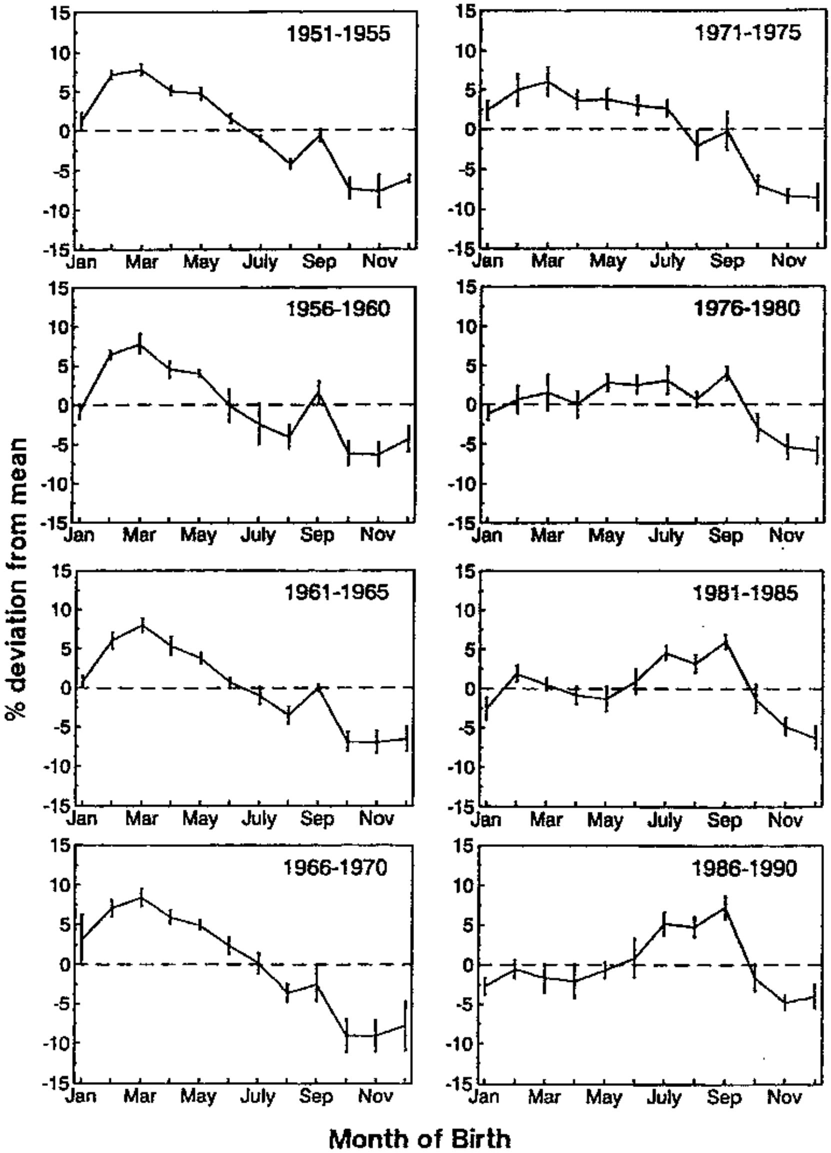

Fig. 5. Relative birth rates in Germany (1951–90). Reproduced from Lerchl, Simoni, M. & Nieschlag, E. (1993) [Changes in seasonality of birth rates in Germany from 1951 to 1990. *Naturwissenschaften* **80**, 516–518], with kind permission of Springer Science and Business Media.

The Netherlands

In contrasting the average hours of sunshine between 1931–60 and 1961–90, it is apparent that the more recent period has become cloudier. The period 1961–90 has an annual average of 95 hours less sunshine. The great bulk of this loss extends from March through the month of September.

Until the 1970s, the seasonality pattern for the Netherlands was typically European with a peak of births in the spring months of April, May and June. In the 1970s, seasonality began to change for the Netherlands. It gradually assumed the American pattern with greater numbers of births occurring later during the late summer months, notably September (Haandrikman, 2004). How did this happen? Most likely it has occurred because of changing seasonal ELI. It must be remembered that a lag exists between exposure to ELI and conception. In this case, the months in which entrainment may have occurred – April–May–June – began to lose sunshine. As a result, there were fewer conceptions during the next three months of July, August and September. This, of course, produced fewer births nine months later in April–May–June. On the other hand, the months of Oct–Nov–Dec were able to retain their normal hours of sunshine. Relative to the previous seven months, Oct–Nov–Dec were months of increased ELI. With this relative increase in ELI, there were more conceptions three months later producing an increased number of births in the forthcoming summer. Remarkably, there is even further evidence of the effect of ELI. It is in the month of February. There is a secondary increase in births for February. There is also a slight increase in ELI for February. In this additional example, increased ELI in February produces an increased number of conceptions three months later, which in turn results in slightly more births the following February.

This transition of seasonal ELI, and its subsequent displacement of seasonal conceptions for both Germany and the Netherlands, was precisely forecasted by Cummings (2002, 2003).

Discussion

These results indicate that a seasonal change in peak conceptual months may be linked to previous changes in seasonable environmental light intensity. Conversely, a pronounced change in seasonal ELI signals a forthcoming change for peak months for conceptions.

No doubt, the transitory nature of conceptions for both Germany and the Netherlands in the 1970–80s closely mirrored concurrent changes in seasonal ELI. During that time, the increase in the number of conceptions in December most likely resulted from increasing ELI during the previous Sep–Oct–Nov (Fig. 4). An increase in December conceptions would, of course, produce an increase in the number of births in the following September. Likewise, the decline in March births most likely derives from declining levels of ELI during the quarter Mar–Apr–May (Fig. 2). Cloudier spring months may have also diminished the effect of photoperiod. With decreased ELI during Mar–Apr–May, there would be fewer June–July conceptions. With decreased June–July conceptions, there would be fewer March births. A key point is that there is a lapse of about three months between exposure to ELI and the manifestation of conceptions.

There is a striking similarity between the transition of births in Germany and the Netherlands in the 1970–80s and the transition of US births in the 1930–40s. In both cases, there was a concurrent and underlying change in seasonal ELI. As the quarter

Sep–Oct–Nov became brighter in both locations, it accentuated November–December as having the most conceptions. This, of course, further increased the number of births the following September. Interestingly, there was an overall loss in ELI for both locations.

While the evidence from this study is compelling, particularly in consideration of previous predictions, it is far short of being factual. A host of other researchers must either confirm or falsify the ELI/PP hypothesis. Perhaps the most direct falsification would involve examples in which seasonal changes in seasonality were not preceded by seasonal changes in ELI. Proving the reverse would be equally reliable in demonstrating that major changes in seasonal ELI have not influenced seasonality.

On another note, nearly 35 United States sites (Cummings, unpublished data) have been investigated for the positive relationship between increased ELI and seasonality. In every instance this relationship was found to hold true. The lag, or ERP, between exposure and conception is 1–2 months for southern states and 2–3 months for the most northern ones. The most disturbing finding is the one for central California in which the results simply agree too well. There are highly significant positive correlations ($r=+0{\cdot}89$ and higher) between ELI and seasonality for all the central California locations that were tested. While there are significant correlations with an ERP of two months, the most significant ones occur at three months. At this somewhat mid-latitudinal location, it was thought that the bulk of conceptions would occur after an exposure of 1–2 months to increased ELI. Instead, they seem to occur after an exposure of 2–3 months. This finding is puzzling because it seems at odds with the notion that the ERP increases with increasing latitude. The air quality in the San Joaquin Valley contains unusually high levels of particulate matter (PM 2·5 and PM 10), which could be a factor in producing a slightly longer ERP. The possible influence of this condition is unknown and much further investigation is required.

There is also a pressing need for further study regarding the physiological effect of increased ELI/PP on the human endocrine system. There are no known measurements of seasonal ELI. Seasonal luminosity values must be inferred from other meteorological data. These data are but broad, crude measurements of ELI.

A first step might involve correlating ELI and seasonality on a larger scale. Many institutions, public and private, have the data, expertise and resources necessary to conduct such a study. If the results of such studies confirm the basic ELI/PP hypothesis, then we should consider many of the issues that broad statistical studies cannot address. For example, we do not know the threshold levels in which ELI/PP may trigger synchronization or promote fertility. We cannot be certain that increased ELI/PP has enhanced fertility or merely shifted and synchronized menstrual cycles. We do not know if exposure at a certain time of day is significant. Nor do we know if a segment of women in a given population is unusually susceptible to increased ELI. Perhaps age is a factor. We certainly don't know the extent of any male contribution to seasonality. Could there be another aspect of the visual spectrum that comes into play? We need to measure accurately the ELI/PP ratio at various latitudes, by the season of the year, by elevation (increased elevation will increase ELI), and by airborne particulate matter, which may diminish ELI. Furthermore, precise data ELI need to be collected long-term from a variety of geographical locations. These and many more questions need to be addressed. In so doing, the welfare of humankind will most certainly be advanced.

The ELI/PP hypothesis provides an excellent explanation for human conceptual, or birth seasonality. Its greatest utility, however, lies in the fact that it is a testable, quantifiable hypothesis having predictive power. A seasonal change in peak conceptual months should be linked to previous changes in seasonable ELI. Conversely, a pronounced change in seasonal ELI signals a forthcoming change in peak months for conceptions. If seasonality patterns appear to be stable, then most likely the underlying ELI has been stable. If after careful review these conditions should prove fallacious, then the ELI/PP hypothesis should be discarded.

Conclusion

The results from the present study are unambiguous, and confirm an earlier prediction (Cummings, 2002, 2003). The shift in peak conceptual months in Germany and the Netherlands during the 1970–80s most likely results from concurrent changes in seasonal ELI. The transition for both Germany and the Netherlands is very similar to that of the US during the 1930–40s. Most probably, the major and underlying cause for worldwide birth seasonality, or conceptions, derives from seasonal increases in ELI at lower latitudes and ELI/PP at higher ones. This, of course, requires independent confirmation. Social influences may also play a secondary role in human birth seasonality. If the ELI/PP hypothesis can be discounted, exploration of social and other biological determinants should be given precedence. At this point, however, there seems no justification for discarding or minimizing the ELI/PP hypothesis. Further research is required, especially with regard to more precise measurements of ELI and its physiological effect on the human endocrine system.

Acknowledgments

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