A POSSIBLE INTERPRETATION OF THE SYNCHRONOUS FLASHING OF FIREFLIES

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I. THEORETICAL AND HISTORICAL

Luminescence in living organisms has rarely failed to excite the curiosity and wonder of mankind. The records of travellers and explorers frequently contain accounts of various forms of the phenomenon and of its presence in many different varieties of animal life. There have also appeared from time to time a large number of scientific descriptions and explanations relating to the biological function, the chemical production, and the characteristic conditions of its occurrence. In 1910 Mangold (18)[1] was able to collect 649 titles on the subject and in the last decade several scores of additional contributions must have appeared. We are not here concerned, however, with the general subject. Some considerations, like the biological function of the phenomenon and the chemical nature of it, may have important relations to the discussion but time forbids a more detailed examination. Suffice it, then, to remark that among insects it is claimed, first by Osten-Sacken (23), then by McDermott (17) and Mast (19), that luminescence is very likely a secondary sex characteristic, especially so in the fireflies (Lampyridae). Recently Harvey (12) has also reported on the chemical changes that take place during the flashing.

But we are chiefly interested in the problem of the concerted behavior of groups of fireflies and with the published statements regarding this peculiar action. It is claimed in many independent reports that there exists at times a certain unusual synchronism of flashing. Often this synchronism is called rhythmical. In the course of discussion synchronism of action has been described in many different forms of animals, notably the swinging movements of web-worms (16, 24), the rising and falling of harvestmen (Phalangidae) (22, 30), the beating of the wings of the pelican (30), the swaying of the bittern in the grass (9), the wriggling of bees at the entrance of

the hive (11), the knocking of the heads of ants against dry leaves (20, 26), the chirping of crickets (Grillidae) (20, 5), the clucking of frogs (2), and the movements of plant lice, of fireflies on the wing, and even of sensitive plants (2).

In examining these reports the psychologist becomes aware of certain features familiar to him in his study of observation and of testimony; and the writer, having acquainted himself with the subject of rhythm, has taken an additionally keen interest in the discussion. A few years ago he made a special investigation into the problem of visual rhythms and discovered in the present question some elements common also to his former experiments.

First of all, then, as to matters of general psychological significance, we may note these:

1. The observations for the most part occur under uncritical conditions. In some respects the circumstances are akin to those accompanying the observation of many mediumistic performances. In a majority of the reports the writer has noticed an emotional attitude and the description of conditions bordering on the romantic. For example we read:

"We sat gazing enraptured on a pyramid of living light, suspended, as it were, by threads of fairy gold. On a high black walnut tree there had gathered myriads of fireflies, which moving through the dark foliage as if to the time of some enchanter's music, presented a scene of exquisite loveliness, which it is impossible to describe. As the fairy mass revolved, now up, now down, then round as to the measured time of a dance, my companion in ecstasy exclaimed, 'Captain, I would work twelve months for nothing to see such a sight as this.' " (28)

"At one moment every leaf and branch appears decorated with diamond-like fire; and soon there is darkness, to be again succeeded by flashes from innumerable lamps which whirl about in rapid agitation. If stars be the

[1] Numbers in parentheses refer to bibliography at the close of the paper. Page references were not deemed necessary because of the brevity of most of the articles cited.

poetry of heaven, earth has nothing more poetic than the tropical firefly." (6)

"On approaching in canoes, a scene of wondrous beauty presented itself. The light was due to miniature lamps of several thousands of fireflies which were holding festival over what appeared to be a breeding ground." (13)

"As the stage rounded one of the numerous curves on the grade there appeared on our left, apparently in motion, a ghostly incandescence which came and went in regularly repeated flashes and intervals of darkness. The appearance was uncanny and was plainly visible to all the passengers in the stage." (21)

The writer has never witnessed synchronic flashing of this sort but he is convinced that its first appearance must throw the observer into an attitude of astonishment at the beauty of the effect. As our experiments later to be described indicate, the same result has been produced even under artificial conditions of the laboratory. And since few of the reported observations have been repeated, statements concerning the phenomenon may be made without being subject to verification under the same conditions.

2. Again, with few exceptions, notably those of Morse (21) and Hudson (13), the synchronism was noticed by but a single observer in any one case. Concerning some of the conflicting points in the several reports there can be therefore no safeguarded confirmation. As some of the statements indicate, at any rate, the phenomenon is in most places of observation particularly rare in occurrence. Allard (1) thinks that "one may consider himself fortunate if he has observed the phenomenon even once in a lifetime, his observation having occurred more than a dozen years ago, and Morse (20) first reported an experience of fifty years ago. Even though there are a good many independent reports of different occasions, an instance simultaneously reported by several individuals is rare in the literature.

3. This scarcity of testimony concerning the identical event is furthermore embarrassed by conflicting reports

on essential points. The debate on some of these points has already been begun in the literature, but no conclusion agreeable to all has been drawn.

(a) There is the widest divergence of opinion regarding the regularity of the synchronism. If some of the fireflies flashed in unison, how many in proportion were 'out of step'? There was of course no check on the apparent regularity of the synchronism. We know, especially from the work of MacDougall and Woodrow that in rhythmical performance variations from strict time can physically occur without a perceptible difference in the maintenance of the rhythm. The quotations which follow indicate positions assumed on this question by the observers.

"There must have been several thousand insects in each tree, yet the synchronism was so perfect that rarely or never did a single firefly flash at the wrong time." (25)

"From time to time, as if moved by a common impulse, great numbers would flash so closely in unison over the entire field that an extensive sheet of tiny light-points would gleam upon the vision for a moment—and then vanish." (1)

"The majority of the fireflies were flashing in unison but there were some which did not time their flashes with the majority." (4)

"The flashes were not perhaps as regular as an army officer would like to see in regimental drills but were so rhythmic that any one would take note of their action." (20)

"I frequently noticed that small trees and shrubs would be more aglow at certain times than at others, but I never happened to observe a time when a small tree or shrub was all alight one instant and dark the next. In my experience there were always some fireflies flashing in the *'dark'* periods. The times of greatest light occurred when the greatest number of varying flashes coincided." (10)

"* * * It was soon evident that while at a given instant one tree may have been more highly illuminated

than the other, there was nothing approaching periodicity in the phenomenon, and no continuation of it was noticed." (16)

"During these visits we noted that the illumination was never due to a truly synchronous lighting of the lamps of those fireflies engaged in the display but was always of the nature of wave motion spreading out from one or more centers * * *. Strictly speaking there was no *measured* regularity in this concerted response and therefore no *true rhythm.* * * *" (13)

In the most recently reported experimental investigation in the subject, the Snyders (27) observed a regularity in the synchronism with a variation of only a tenth of a second in the flash of fireflies flying in a strata of a uniform temperature coefficient.

(b) Variations occur also in the statements concerning the duration of the synchronism. Some say that the effect lasted for a considerable length of time, others that it appeared sporadically. One of the quotations given above (16) referred to the fact that there was no continuation of effect noticeable. In one report we note that the synchronism did not begin at the first appearance of the flashing:

"After a while a most remarkable synchronism in the flashing appeared to take place * * *. This remarkable synchronism in the flashing sometimes continued several times in succession, * * *." (1)

(c) The question of alternate illumination of trees, in addition to the synchronous effect in any one tree, also arises. There seems to be, in other words, a spatial factor in the distribution of the periodical effect.

In respect to the problem of rhythm, we are at once confronted with several important factors. There can be no rhythm, of course, unless there is accentuation of some member in the measure. It is likely therefore that whenever the term is used in these discussions there is meant simply a periodicity or synchronism, *i. e.,* the wider usage of the term common in some connections, as physiological rhythm, geological rhythm, or, as is less likely, there is already a tacit admission that a rhythm

exists, but that it is subjective as regards the observer. This explanation has already been suggested by Craig (9) who refers also to the similar theory advanced in the Dolbear-Shull controversy regarding crickets. It were better to restrict the effect to that of synchronism.

Other explanations have not been lacking. The earlier writers did not hesitate to attribute to the lower animals a "fine sense of rhythm on the part of each individual" (30). Both by implication and by direct statement the opinion is expressed that the control of the performance is consciously executed. One writer discusses the subject in connection with crickets (5):

"It is now a question as to whether these crickets perceive the rhythm which is so pronounced in the regular sequence of their chirpings. I believe they must, for it is quite evident that they hear and respond to the peculiar rhythmical chirpings of their kind, which have become the common language of the species. If they are able to recognize the notes of their kind, it is reasonable to believe that the rhythmical character, as well as pitch, manner of delivery, and even more subtle tonal differences enter into the recognition."

It is almost gratuitous to assign rhythmic perception to the lower organisms. According to Morgan it is not safe to explain animal action on any higher mental level than is necessary. Swindle (29) seems to think that the sense of rhythm in the human species does not show traces of inheritance. And the question whether savages have a more pronounced sense of rhythm because, Delacroze fashion, they can often maintain complicated rhythms side by side, has not yet received a final answer! In the case of fireflies the added difficulty of seeing the rest, except in the few instances of a spreading effect from several foci (13, 22) is presented. The difficulty of explaining the phenomenon on the basis of a selective sex function is materially increased by the synchronism itself (16). To the writer it would seem that if the flashing is related to the sex activity of the males, as the work of Mast (19) seems to indicate, it cannot be of direct causal assistance, but only of secondary import-

ance in the sense of a by-product. And it is furthermore apparent from the researches of Harvey (12) that the release may be very regular provided that the physico-chemical conditions are such that the oxidation of luciferin can be resumed at periodically recurring intervals. It is not necessary therefore to take the extreme view that the flashing is due to movements of the eyelids of the observer, as Laurent concluded (15), or that the matter rests largely upon the suggestion of the observer's mind as Craig infers (9), or that, as Gates remarks (10), "complete synchronism in the flashing of a group of fireflies is simply a very rare accident, occurring when the flashes of the individuals chance to come at the same time."

II. EXPERIMENTAL

The writer believed that, aside from the varying circumstances attendant upon the observations as noted, a reasonable item in the explanation of the phenomenon in its psychological aspects was the well-known tendency of the human mind to integrate its experiences. If the ticks of a metronome are heard at first in a monotonous and unaccented fashion, soon they will be measured off subjectively into groups; if any unevenness should occur in these beats, it would be overlooked and the grouping would continue as before; and if a number of metronomes were set off at respectively different rates, the subject hearing them all at once would bring order out of chaos and begin to superimpose a grouping on the irregularly beating complex.

The assumption made, then, was this: suppose, as some writers stated, there should be several coincidences among a large number of firefly flashings in a given place. This would be so striking that the periods of darkness might seem in comparison more or less complete; and it would then tend to set the mind of the observer in the direction of subsequent grouping of flashes in patterns supplied, for the most part, by himself. In the case of observers whose rhythmicizing tendencies were not so strong—they are never entirely wanting in the normal human mind—the report would take a different turn

from those of others more emphatically inclined in this direction.

Apparatus. It was our task to reproduce on a smaller scale and under laboratory conditions the effect described in the above reports. That the appearance was startling and beautiful most of our observers spontaneously remarked. Twenty small, 15 watt tubular incandescent lamps were mounted irregularly over a wooden framework on candelabra bases. Covers for these lights were then made out of mailing tubes with one end sealed and a hole punched in this end in diameter a little larger than that of the ordinary pin-hole. The inside of the tubes was lined with white bristol board to increase the reflection. But great care was taken to stop all light-leaks, even thoes only faintly visible in the dark-room. The entire arrangement subtended a visual angle of about 25°, the observer sitting about 5 meters away from the framework. The framework was eccentrically pivoted on the wall opposite the observer so as to disturb any tendency to memorize the pattern of arrangement. When the experiment was not under way, a curtain hung over the apparatus in order to prevent the possibility of an inadvertent exposure of the apparatus to the observer. There was provided also a small greenish light mounted near the center of the framework which served to give the observer the approximate center of fixation. A telephone cable with a separate strand for each light carried the connections to an adjoining dark-room where the experimenter was stationed and where the control apparatus was located. This consisted principally of a small horizontal brass drum driven by a very smoothly running clockwork and governor. On the drum were mounted strips of paper with perforations for the contacts made through twenty separately connected pointers. Whenever one of the pointers passed over a hole in the paper the electric circuit for its particular lamp was closed and the lamp would flash. A main switch and a switch for the momentary flashing of the fixation lamp completed the apparatus in the experimenter's room.

Observers. Observers were recruited from the staff, from the graduate students in the Department of Psychology, from the students in the intermediate laboratory, and from the members of a few elementary classes. There were more than a dozen all told; and they ranked in training from naive observation to the capacity for careful analysis of mental processes. With one or two exceptions, which were noted in our results, the observers were uninformed concerning the problem of the experiment or the character and disposition of the apparatus.

Procedure. The experiments lasted through the greater part of the year 1919-1920 in the course of which time several modifications in the procedure were made. In the early series only five lights were used. They were flashed on in irregular order and no two in unison. Since we were working with a limited number of lamps, at most only twenty, to produce an effect equivalent to that under natural conditions we had to increase the speed of flashing to about one per second; the duration of the flash equal to .5 sec. and the intervals between flashes of the same duration as the flashes. The Snyders give the most reliable value as to flash and interval: 15 flashes per min. and a 6 sec. duration for the interval. We are now continuing the experiment with these longer time values.

In every experimental series the observer was seated in the dark-room, allowed to rest for about five minutes to permit after-images to disappear and to become "dark adapted," and he was then told to describe as accurately and analytically as possible the effect produced. He was told that a warning signal would appear at about the center of the field which he was to observe and at about three second interval before the observation was to begin. Cotton was inserted in his ears so that no possible noise from the apparatus in the adjoining room could form the basis of grouping even though heard through the closed door. At the end of the series before the light was again turned on the curtain was drawn over the framework suspended on the wall.

From a simple series of five lights, each one flashing at its own peculiar rate, the number of lights flashing in

this manner was gradually increased in successive series, until all twenty lights were in operation. In all cases the length of the flash was the same but the intervals between the flashes varied from .5 sec. to 2.5 sec. in .5 sec. increments. The temporal distribution of all the lights was such that only two out of the twenty could flash at the same instant.

In a final series we tried the effect of continuing a rhythmical grouping that was given four times at the beginning of the series, but passing thence into the utmost irregularity of flashing.

Results. It was curious to see the emotional effect of all of our series on the observers. Some of it undoubtedly was due to the appearance of these odd and silent flashings on the wall of a dark-room. But more curious still were the spontaneous associations with fireflies. Some of the remarks, as made by different observers, follows:

"Impression of lightning bugs flitting."
"Idea of lightning bugs."
"I had the idea that I was watching fireflies at night or butterflies flitting about."
"Lightning bugs on a warm night."
"Fireflies in summer."

These statements suggested to the writer that the apparatus which served to isolate the natural conditions on a small scale in the laboratory had not taken away the essential significance of the experiment by carrying the abstraction too far. The fireflies were psychologically there.

But more important is the result derived from nearly every series and from every observer showing the strong tendency to organize the experience into patterns or groups. Sometimes it was a spatial pattern which reminded one of the several sets of trees or shrubs which in the narratives were illuminated in turn, for frequently the introspective reports would reveal a visual arrangement which was superimposed mentally on the experience as it came. As one observer put it, "an indistinct impression of a pattern that recurs and yet cannot be de-

scribed," was experienced. These patterns fulfilled the conditions, too, of 'complete unison' described in the narratives. As one observer remarked, "I was impressed by the lightness and then the extreme darkness as the lights were turned on and off", when as a matter of physical fact, the apparatus did not furnish any interval when there were no lights lit.

In most cases, however, the organization took the form of a temporal arrangement much like our ordinary rhythmical experiences, as some of the selected introspections show:

"I was conscious of more order in the switching on and off of the lights this time."

"It suggested a rhythmical procedure on the violin."

"The idea occurred which meant a rhythmical swinging of church bells in a belfry."

"The idea of playing of piano was called to mind. The brief flashes of light seemed similar to the light touches given the notes when a fast piece is played."

Altogether while no mention of rhythm had been made, the reference to it was very common. This rhythmical grouping, involving a subjectively produced 'synchronism', was all the more marked when the observer was carried along by the suggestion of the initial groupings which were actually produced in the last series.

Summary and Conclusion. Our experiments seem to indicate that under conditions which simulate the natural ones there is a strong tendency to read into the experience, that is presented in a disorganized manner, something of order and regularity. We are continually associating and integrating into groups. This is as true of our simple impressions as it is of our higher and more complex processes of reasoning. A treeful of fireflies flashing each one to his own sweet will is not faithfully observed in the first place nor faithfully reported in the second place. The writer sees nothing to invalidate the empirical results of the Snyders or of Mast, nor does he find himself inclined to doubt the statements made concerning the apparent temporary coincidence of the thousands of flashes that is, for a brief space of time;

but he is inclined to question the reports of prolonged and of absolutely unified flashing when it is implied that the prolongation and the unification lies outside of the mental activities of the observers.

In any event, the results of our own experiments are quite positive; we did get the reports of rhythms from our observers in the majority of cases when there were no physical rhythms presented. The rhythms were both of the visual pattern and of the temporal type with some auditory imagery serving as accompanying ideas. In the first type the pattern was principally extended in space, although repeated in time, while in the second there was mainly a synchronism without visual extension.

The only criticism then can come from the conditions of the experiment in that the necessary abridgment of factors, such as the reduction in numbers of flashes, their change in time, and the attitude of the observer, has produced an artificial result, or at least a result incomparable with the natural effect. We are now proceeding with further modifications in these directions, and we offer the present report temporarily as a suggestion toward a possible solution on the psychological side, so that in the final analysis, if there is to be one, we shall be able to recognize on the physical side the influence of temperature as a regulator of the chemical oxidation in the presence of an enzyme and on the psychological side the influence of the mental functions of the observer in carrying his report to its proper logical conclusion.

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