Biochemical Pharmacology, Vol. 24, pp. 1193–1197. Pergamon Press, 1975. Printed in Great Britain.

# A COMPARATIVE STUDY OF THE UTILIZATION OF GLUCOSE, ACETATE, GLUTAMINE AND GABA AS PRECURSORS OF AMINO ACIDS BY RETINAE OF THE RAT, FROG, RABBIT AND PIGEON

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(*Received* 25 *October* 1974; *accepted* 20 *December* 1974)

**Abstract**—The distribution of $^{14}C$ among the amino acids aspartate, glutamate, glutamine and GABA, both in the tissues and incubation media, was studied using retinae from the rat, frog, rabbit and pigeon which had been incubated with radioactive glucose, acetate, glutamine or GABA. Tissue free amino acid contents were also measured and the specific activities of the amino acids calculated. All four species metabolized acetate and GABA within a small glutamate pool, since the specific activities of glutamine relative to glutamate were always greater than 1·0. However, in each case glucose carbon entered a large glutamate pool as the RSA of glutamine was invariably less than unity. The ability of [$^{14}C$]glutamine to pass out of retinae and to accumulate in the extracellular fluid in large quantities was not shared by the other amino acids. The implications of this finding are discussed with reference to its significance as a detoxication mechanism for ammonia, and also as a means for glutamine to participate in the synthesis of GABA. Various differences existed between species in the patterns of metabolism of the various precursors, but none of these was so prominent as to permit one to ascribe separate functions to the routes of breakdown of GABA by complex (frog, rabbit and pigeon) and simple (rat) retinae.

The retina is an extremely interesting component of the central nervous system for, in spite of its small size, it has been attributed with such a diversity of neurotransmitter candidates, including acetylcholine [15], dopamine [7, 17, 25, 35] and a variety of amino acids [4, 10, 16, 23, 26, 34–36, 38]. Of these, 4-aminobutyric acid (GABA) has recently received the most attention and it is widely believed that GABA may act as an inhibitory transmitter substance in retinal tissue [1, 10, 12, 16, 29–30, 31, 35, 37]. Certainly all of the retinae from the different species that have been studied thus far have been found to possess the enzyme systems normally associated with the GABA shunt [9, 10, 14, 18, 30], but it is impossible to say from these findings alone whether GABA is likely to have a transmitter role in any of these tissues, since its metabolism is also intimately bound up with the exergonic processes of the cell and this may turn out to be its main function. One approach that could help to clarify the situation would be to use biochemical techniques to establish that separate pools of GABA and its related metabolites exist in the retina, one of which might correspond to a "transmitter" pool [2]. Initial experiments have already been performed using the isolated rat's retina and these have suggested that amino acid metabolism is indeed compartmented [31] and that exogenous GABA penetrates a tissue pool which appears to be different from those normally entered by more conventional substrates, such as glucose and acetate [32]. This approach may be carried a step further by comparing the metabolism of GABA and other amino acids by retinae from different vertebrate species, as it is now well established that such retinae exhibit an assortment of types of synaptic organization, and it might be expected that the patterns of metabolism of these compounds would vary accordingly [5, 6, 11, 13, 21, 22]. This paper reports the results of such a comparative study and shows that whilst differences in metabolism do exist these cannot be related to a particular retinal type.

## MATERIALS AND METHODS

The species used were Wistar albino rats, frogs (*Rana pipiens*), pigeons and albino rabbits. Animals were killed by cervical dislocation and the eyes rapidly enucleated. The retinae were quickly dissected out into Krebs bicarbonate solution [33] containing 2·78 mM glucose and gassed with a mixture of 5% carbon dioxide in oxygen. Whole retinae were used from rats and frogs whilst fragments of equivalent size were taken from rabbit and pigeon retinae. Care was taken to avoid using the area of the visual streak in the rabbit, and pigeon tissues were separated into the well-defined red and yellow regions. Retinal samples were transferred to 1 ml Krebs solution (approximately 25 mg wet wt of tissue per flask) and given a preliminary incubation at 37° for 15 min, then radioactive metabolite was added and the incubation continued for a further 60 min. After this time the tissues were recovered, washed in fresh Krebs solution for 2 min, weighed on a torsion balance and the radioactive amino acids present both in the tissues and in the incubation media were extracted and measured as described in detail elsewhere [31]. Total free amino acid levels were measured in retinae which had been incubated for 75 min at 37° in the absence of added metabolites by means of an automatic amino acid analyser (Biocal Model 100) [31].

All radioactive materials were obtained from The Radiochemical Centre, Amersham, and these included: D-[U-$^{14}C$]glucose (168 mCi/m-mole), [1-

Table 1. Incorporation of $^{14}C$ from D-[U-$^{14}C$]glucose into amino acids by retinae of different species

| Species | | Glutamate | Aspartate | Glutamine | GABA |
|---|---|---|---|---|---|
| Rat | (dis/min × $10^{-6}$/g) | 0·797 ± 0·079 | 0·327 ± 0·027 | 0·416 ± 0·037 | 0·106 ± 0·014 |
| | | (0·081 ± 0·008) | (0·026 ± 0·003) | (1·118 ± 0·058) | (0·037 ± 0·002) |
| | (dis/min × $10^{-6}$/μmole) | 0·249 | 0·200 | 0·237 | 0·085 |
| | RSA | 1·000 | 0·803 | 0·953 | 0·340 |
| Frog | (dis/min × $10^{-6}$/g) | 0·597 ± 0·060 | 0·140 ± 0·016 | 0·351 ± 0·047 | 0·233 ± 0·024 |
| | | (0·056 ± 0·007) | (0·006 ± 0·001) | (0·325 ± 0·029) | (0·031 ± 0·005) |
| | (dis/min × $10^{-6}$/μmole) | 0·364 | 0·304 | 0·326 | 0·092 |
| | RSA | 1·000 | 0·834 | 0·896 | 0·252 |
| Rabbit | (dis/min × $10^{-6}$/g) | 0·596 ± 0·041 | 0·171 ± 0·022 | 0·325 ± 0·040 | 0·058 ± 0·004 |
| | | (0·021 ± 0·002) | (0·012 ± 0·002) | (1·442 ± 0·101) | (0·050 ± 0·003) |
| | (dis/min × $10^{-6}$ μmole) | 0·368 | 0·256 | 0·326 | 0·047 |
| | RSA | 1·000 | 0·696 | 0·887 | 0·128 |
| Pigeon (red spot) | (dis/min × $10^{-6}$/g) | 1·040 ± 0·057 | 0·244 ± 0·022 | 0·440 ± 0·034 | 0·236 ± 0·023 |
| | | (0·048 ± 0·002) | (0·012 ± 0·002) | (1·050 ± 0·158) | (0·048 ± 0·005) |
| | (dis/min × $10^{-6}$ μmole) | 0·619 | 0·435 | 0·295 | 0·131 |
| | RSA | 1·000 | 0·703 | 0·477 | 0·212 |
| Pigeon (yellow area) | (dis/min × $10^{-6}$/g) | 1·028 ± 0·091) | 0·237 ± 0·018 | 0·379 ± 0·030 | 0·268 ± 0·022 |
| | | (0·041 ± 0·001) | (0·014 ± 0·001) | (1·208 ± 0·109) | (0·038 ± 0·003) |
| | (dis/min × $10^{-6}$/μmole) | 0·571 | 0·414 | 0·277 | 0·177 |
| | RSA | 1·000 | 0·725 | 0·484 | 0·309 |

Whole retinae (rat and frog) or fragments of retinae (rabbit and pigeon) were incubated in 1 ml Krebs solution (approximately 25 mg wet wt of tissue per flask) under an atmosphere of 5% carbon dioxide in oxygen. Following a 15-min preincubation at 37°, 2 μCi D-[U-$^{14}C$]glucose (12 nmoles) were added and the incubation continued for a further 60 min. The radioactivity incorporated into the free amino acids of the tissues and the incubation media (shown in parentheses) was recovered and measured as described previously [31]. The total free amino acid contents of the tissues, but not of the media, were measured as before [31] and were used to calculate the specific activities of the labelled amino acids located inside the tissues (shown above).

Each value ± S.E. is the mean of at least 15 experiments.

Sp. act. = dis/min × $10^{-6}$/μmole.

RSA = sp. act. relative to glutamate.

$^{14}C$]sodium acetate (58 mCi/m-mole), L-[U-$^{14}C$]glutamine (48 mCi/m-mole) and [1-$^{14}C$]GABA (3·14 mCi/m-mole). The sources of all other chemicals used have already been listed [32].

## RESULTS

*Incorporation of $^{14}C$ from D-[U-$^{14}C$]glucose into amino acids.* The syntheses of [$^{14}C$]amino acids from [$^{14}C$]glucose in retinae of four different species are shown in Table 1. Free amino acid contents were measured in control retinae which had been incubated in a similar manner in the absence of labelled substrate (see Table 5) and were used to calculate the specific activities of the radioactive amino acids present in the tissues at the end of each labelling experiment. Total levels of amino acids in the corresponding media were not determined. Table 1 clearly indicates there was a wide variation in the distribution of radioactivity among the amino acids studied, both in those retained within the tissues and in those accumulating in the bathing medium. Glutamate was the most heavily labelled, more especially in the red and yellow areas of the pigeon's retina, but only very small amounts of radioactive glutamate (5–10 per cent of tissue levels) were detected in the incubation medium. [$^{14}C$]glutamine was also readily synthesized from [$^{14}C$]glucose by retinae from all four species

Table 2. Incorporation of $^{14}C$ from [1-$^{14}C$]sodium acetate into amino acids by retinae of different species

| Species | | Glutamate | Aspartate | Glutamine | GABA |
|---|---|---|---|---|---|
| Rat | (dis/min × $10^{-6}$/g) | 1·533 ± 0·142 | 0·505 ± 0·052 | 3·001 ± 0·198 | 0·333 ± 0·027 |
| | | (0·595 ± 0·047) | (0·028 ± 0·002) | (10·356 ± 0·896) | (0·107 ± 0·015) |
| | (dis/min × $10^{-6}$ μmole) | 0·479 | 0·309 | 1·856 | 0·181 |
| | RSA | 1·000 | 0·645 | 3·876 | 0·377 |
| Frog | (dis/min × $10^{-6}$/g) | 0·479 ± 0·032 | 0·114 ± 0·012 | 0·404 ± 0·051 | 0·233 ± 0·039 |
| | | (0·060 ± 0·011) | (0·009 ± 0·001) | (0·768 ± 0·069) | (0·038 ± 0·008) |
| | (dis/min × $10^{-6}$/μmole) | 0·292 | 0·246 | 0·374 | 0·092 |
| | RSA | 1·000 | 0·844 | 1·282 | 0·315 |
| Rabbit | (dis/min × $10^{-6}$/g) | 0·215 ± 0·032 | 0·038 ± 0·003 | 0·273 ± 0·002 | 0·042 ± 0·003 |
| | | (0·019 ± 0·002) | (0·005 ± 0·001) | (0·984 ± 0·011) | (0·028 ± 0·002) |
| | (dis/min × $10^{-6}$/μmole) | 0·133 | 0·057 | 0·274 | 0·034 |
| | RSA | 1·000 | 0·430 | 2·066 | 0·256 |
| Pigeon (red spot) | (dis/min × $10^{-6}$/g) | 0·297 ± 0·009 | 0·065 ± 0·006 | 0·108 ± 0·009 | 0·068 ± 0·004 |
| | | (0·028 ± 0·002) | (0·008 ± 0·001) | (0·254 ± 0·026) | (0·029 ± 0·001) |
| | (dis/min × $10^{-6}$/μmole) | 0·176 | 0·116 | 0·725 | 0·038 |
| | RSA | 1·000 | 0·659 | 4·119 | 0·216 |
| Pigeon (yellow area) | (dis/min × $10^{-6}$/g) | 0·305 ± 0·015 | 0·061 ± 0·005 | 0·126 ± 0·002 | 0·071 ± 0·013 |
| | | (0·025 ± 0·004) | (0·007 ± 0·001) | (0·378 ± 0·007) | (0·025 ± 0·003) |
| | (dis/min × $10^{-6}$/μmole) | 0·169 | 0·107 | 0·920 | 0·047 |
| | RSA | 1·000 | 0·633 | 5·444 | 0·278 |

Experimental details are as for Table 1 except that incubation was carried out for 60 min at 37° in the presence of 5 μCi [1-$^{14}C$]sodium acetate (86 nmoles). Each value is the mean ± S.E. of at least 15 determinations. Figures in parentheses represent the radioactivities recovered in the amino acids present in the incubation media at the end of incubation.

RSA = sp. act. relative to glutamate.

Table 3. Incorporation of $^{14}C$ from L-[U-$^{14}C$]glutamine into amino acids by retinae of different species

| Species | | Glutamate | Aspartate | Glutamine | GABA |
|---|---|---|---|---|---|
| Rat | (dis/min × $10^{-6}$/g) | 20·664 ± 2·320 | 5·477 ± 0·495 | 26·323 ± 2·591 | 2·406 ± 0·540 |
| | | (19·745 ± 3·216) | (0·478 ± 0·033) | (N.D.) | (0·873 ± 0·042) |
| | (dis/min × $10^{-6}$/μmole) | 6·453 | 3·352 | 16·279 | 1·304 |
| | RSA | 1·000 | 0·519 | 2·523 | 0·202 |
| Frog | (dis/min × $10^{-6}$/g) | 17·220 ± 1·381 | 1·929 ± 0·301 | 18·242 ± 1·611 | 10·303 ± 1·241 |
| | | (5·495 ± 0·506) | (0·434 ± 0·045) | (N.D.) | (2·174 ± 0·286) |
| | (dis/min × $10^{-6}$/μmole) | 10·500 | 4·184 | 16·922 | 4·064 |
| | RSA | 1·000 | 0·399 | 1·612 | 0·387 |
| Rabbit | (dis/min × $10^{-6}$/g) | 11·968 ± 1·034 | 1·150 ± 0·066 | 18·632 ± 3·210 | 2·017 ± 0·180 |
| | | (1·378 ± 0·134) | (0·049 ± 0·002) | (N.D.) | (0·244 ± 0·024) |
| | (dis/min × $10^{-6}$/μmole) | 7·383 | 1·724 | 18·688 | 1·641 |
| | RSA | 1·000 | 0·233 | 2·531 | 0·222 |
| Pigeon (red spot) | (dis/min × $10^{-6}$/g) | 44·148 ± 3·748 | 8·907 ± 0·670 | 15·240 ± 1·103 | 3·524 ± 0·351 |
| | | (7·551 ± 0·978) | (0·647 ± 0·017) | (N.D.) | (1·662 ± 0·094) |
| | (dis/min × $10^{-6}$/μmole) | 26·279 | 15·877 | 102·282 | 1·958 |
| | RSA | 1·000 | 0·604 | 3·892 | 0·074 |
| Pigeon (yellow area) | (dis/min × $10^{-6}$/g) | 35·715 ± 1·486 | 3·672 ± 0·432 | 17·712 ± 1·234 | 1·807 ± 0·202 |
| | | (7·454 ± 0·160) | (0·348 ± 0·066) | (N.D.) | (1·403 ± 0·087) |
| | (dis/min × $10^{-6}$/μmole) | 19·842 | 6·420 | 129·285 | 1·190 |
| | RSA | 1·000 | 0·323 | 6·516 | 0·060 |

Experimental details are as for Table 1 except that incubation was carried out for 60 min at 37° in the presence of 2·5 μCi L-[U-$^{14}C$]glutamine (52 nmoles). Each value is the mean ± S.E. of at least 15 determinations. Figures in parentheses represent the radioactivities recovered in the amino acids present in the incubation media at the end of incubation.

RSA = sp. act. relative to glutamate.

N.D. = not determined.

but, by contrast with [$^{14}C$]glutamate, the highest levels of this compound were found extracellularly. The specific activities of intracellular glutamine were similar in all four species and were always less than those of glutamate (i.e. relative sp. act., RSA < 1·0).

The retinal levels of [$^{14}C$]aspartate decreased in the order rat > pigeon > rabbit > frog, whereas the tissue levels of [$^{14}C$]GABA decreased in the order pigeon > frog > rat > rabbit. In each case only small quantities of these amino acids were present in the incubation media following a 60-min period of incubation.

*Incorporation of $^{14}C$ from [1-$^{14}C$]sodium acetate into amino acids.* Similar experiments were performed using [$^{14}C$]acetate as the substrate. The results are listed in Table 2. As with glucose, the ability of acetate to act as a precursor for the biosynthesis of amino acids in the retina varied widely with the species; the incorporation of $^{14}C$ from [$^{14}C$]acetate into the four amino acids investigated decreased approximately in the order rat > frog > pigeon > rabbit. With all four species the concentrations of [$^{14}C$]glutamine were higher in the media surrounding the tissues, whilst the other [$^{14}C$]amino acids passed out of the retinae less readily during a 60-min period of incubation. The production of [$^{14}C$]glutamine always exceeded that of [$^{14}C$]glutamate, with the result that the RSA of glutamine inside the retinae was always greater than 1·0.

*Incorporation of $^{14}C$ from L-[U-$^{14}C$]glutamine into amino acids.* Table 3 indicates that [$^{14}C$]glutamine was taken up and extensively metabolized by retinae of all four species, the principal metabolite being [$^{14}C$]glutamate. The specific activities of [$^{14}C$]glutamate were considerably higher in the pigeon's retina (approx. range 19–27) than in retinae from rat, frog

Table 4. Incorporation of $^{14}C$ from [1-$^{14}C$]GABA into amino acids by retinae of different species

| Species | | Glutamate | Aspartate | Glutamine | GABA |
|---|---|---|---|---|---|
| Rat | (dis/min × $10^{-6}$/g) | 0·936 ± 0·019 | 0·532 ± 0·052 | 2·950 ± 0·076 | 20·388 ± 2·085 |
| | | (0·438 ± 0·020) | (0·082 ± 0·003) | (7·264 ± 0·121) | (N.D.) |
| | (dis/min × $10^{-6}$/μmole) | 0·292 | 0·326 | 1·824 | 11·050 |
| | RSA | 1·000 | 1·115 | 6·247 | 75·685 |
| Frog | (dis/min × $10^{-6}$/g) | 0·548 ± 0·010 | 0·975 ± 0·052 | 0·648 ± 0·038 | 11·560 ± 0·984 |
| | | (0·292 ± 0·027) | (0·108 ± 0·014) | (2·998 ± 0·273) | (N.D.) |
| | (dis/min × $10^{-6}$/μmole) | 0·334 | 2·115 | 0·602 | 4·166 |
| | RSA | 1·000 | 6·333 | 1·802 | 12·473 |
| Rabbit | (dis/min × $10^{-6}$/g) | 0·410 ± 0·038 | 1·187 ± 0·102 | 2·158 ± 0·021 | 14·115 ± 1·582 |
| | | (0·126 ± 0·011) | (0·052 ± 0·001) | (6·400 ± 0·671) | (N.D.) |
| | (dis/min × $10^{-6}$/μmole) | 0·253 | 1·780 | 2·164 | 11·485 |
| | RSA | 1·000 | 7·034 | 8·553 | 45·395 |
| Pigeon (red spot) | (dis/min × $10^{-6}$/g) | 0·508 ± 0·021 | 0·330 ± 0·014 | 0·524 ± 0·050 | 17·531 ± 1·722 |
| | | (0·754 ± 0·041) | (0·221 ± 0·019) | (5·600 ± 0·474) | (N.D.) |
| | (dis/min × $10^{-6}$/μmole) | 0·302 | 0·588 | 3·517 | 9·739 |
| | RSA | 1·000 | 1·947 | 11·645 | 32·250 |
| Pigeon (yellow area) | (dis/min × $10^{-6}$/g) | 0·562 ± 0·051 | 0·294 ± 0·020 | 0·720 ± 0·080 | 18·774 ± 1·010 |
| | | (0·826 ± 0·077) | (0·272 ± 0·018) | (7·112 ± 0·951) | (N.D.) |
| | (dis/min × $10^{-6}$/μmole) | 0·312 | 0·514 | 5·255 | 12·368 |
| | RSA | 1·000 | 1·647 | 16·844 | 39·640 |

Experimental details are as for Table 1 except that incubation was carried out for 60 min at 37° in the presence of 2 μCi [1-$^{14}C$]GABA (637 nmoles). Each value is the mean ± S.E. of at least 15 determinations. Figures in parentheses represent the radioactivities recovered in the amino acids present in the incubation media at the end of incubation.

RSA = sp. act. relative to glutamate.

N.D. = not determined.

Table 5. Free amino acid levels in retinae of different species

| Species | Amino acid concentration (μmoles/g wet wt) | | | |
|---|---|---|---|---|
| | Glutamate | Aspartate | Glutamine | GABA |
| Rat | 3·202 | 1·634 | 0·808 | 1·845 |
| Frog | 1·640 | 0·461 | 1·078 | 2·535 |
| Rabbit | 1·621 | 0·667 | 0·997 | 1·229 |
| Pigeon (red spot) | 1·680 | 0·561 | 0·149 | 1·800 |
| Pigeon (yellow area) | 1·800 | 0·572 | 0·137 | 1·518 |

Freshly dissected retinae from the different species were incubated for 75 min at 37° in Krebs bicarbonate solution (approximately 25 mg wet wt tissue/1 ml). The free amino acids were then extracted and measured as described previously (see Methods section) using an automatic amino acid analyser. This method was not operating at sufficient sensitivity to give reproducible results for the concentrations of these amino acids in the incubation media. Each value is the mean of at least 12 determinations.

S.E. were in the range 8–11 per cent (not shown).

or rabbit (approx. range 6–11). The pigeon's red spot was found to produce significantly greater amounts of [$^{14}$C]glutamate than the yellow area ($P < 0.01$), although there was no corresponding difference in the concentrations of this amino acid in the media bathing the two tissues.

Both the rat's retina and the pigeon's red spot were particularly active at labelling aspartate, whereas the formation of [$^{14}$C]GABA from [$^{14}$C]glutamine was most pronounced in the retina of the frog. The concentrations of both these amino acids in the incubation media were generally similar to those labelled from [$^{14}$C]acetate and [$^{14}$C]glucose. The pigeon's red spot synthesized roughly twice as much [$^{14}$C]aspartate and [$^{14}$C]GABA as did the yellow area. This difference was found to be highly significant ($P < 0.001$) and did not appear to be related to the original amounts of glutamine taken up by the two areas (see Table 3), nor to their endogenous glutamine contents (see Table 5), since these were closely similar in both cases.

*Incorporation of $^{14}$C from [1-$^{14}$C]GABA into amino acids.* The accumulation of [$^{14}$C]GABA decreased in the order rat > pigeon > frog > rabbit (Table 4). The metabolism of [$^{14}$C]GABA yielded higher amounts of [$^{14}$C]glutamine than either labelled aspartate or glutamate. In the experiments with frog retina the RSA of glutamine was only slightly higher than unity (RSA = 1·8), whilst with the other species the RSA of this compound was consistently much larger (range 6–16). The amounts of [$^{14}$C]glutamine accumulating in the media were always several times greater than those present inside the tissues.

The next most abundantly labelled amino acid was found to glutamate in the case of rat and pigeon retinae, and aspartate with frog and rabbit retinae. The highest extracellular concentrations of these compounds occurred with pigeon retinae.

## DISCUSSION

The above results confirm that retinal tissues are capable of utilizing substrates with a variety of carbon skeletons for the biosynthesis of amino acids. Also, they show that the uptake and interconversion of GABA and glutamine takes place readily in all of the species studied. These data lend additional weight to the hypothesis that, if GABA subserves a transmitter function in the retina, then any GABA which is liberated during the course of neuronal activity may not necessarily be recaptured by reuptake into GABA-neurones, but may first be metabolized by glial cells to give glutamine, which is then used as a precursor for GABA resynthesis [2, 3, 31]. Alternatively, the fact that large amounts of labelled glutamine always accumulated extracellularly may point to a different role for this amino acid, since it could represent the means whereby any ammonia, which is produced as the result of nervous activity within the retina, is detoxicated and removed from the tissue [27, 28, 40].

Retinae from all four species exhibited compartmentation of glutamate metabolism. Thus acetate and GABA appeared to be metabolized within a small pool of glutamate, with which glutamine synthesis was closely associated, because the specific activity of glutamine derived from both of these substrates was always greater than that of glutamate. Carbon from glucose, on the other hand, passed into a larger pool of glutamate, whose specific activity was invariably higher than that of glutamine [2, 8, 31].

Autoradiographic studies of GABA uptake have shown that exogenous GABA is taken up into neurones (mainly amacrine cells) of the more complex retinae of the frog [39] and the pigeon [20], but into the glial element of the simple rat's retina [19, 24]. However, although separate anatomical sites for the uptake of GABA may exist in complex and simple retinae, there is no indication from the present data of any obvious differences in the way that these retinal types metabolize GABA or various other substrates.

The photoreceptors of the pigeon's red spot are mainly cones, whereas the yellow area contains a mixed population of rod and cone cells. The only marked difference in the metabolism of these two regions was the greater conversion of glutamine into aspartate and GABA by the fraction richest in cones. The possible functional significance of this observation is not known, but it is worth noting that similar differences between the metabolism of the mixed rod and cone retina of the frog and the predominantly rod retinae of the rat and rabbit were not found.

*Acknowledgement*—The author is grateful to the Wellcome Trust for a grant for radiochemicals.

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