Effect of dietary amino acid content on canine learning and behaviour

It has been shown in humans and other species that some amino acids in the diet directly influence brain activity by enhancing or reducing the rate of synthesis of different neurotransmitters. The level of tryptophan – and other large neutral amino acids provided in the diet – can influence the brain concentrations of these amino acids and subsequently alter behaviour.

Mammals are unable to synthesise tryptophan and, therefore, levels in the brain depend on the presence of adequate dietary concentrations. Tryptophan is converted in the terminals of certain neurons into the indolamine serotonin, one of the monoamine neurotransmitters; the synthesis of serotonin has been shown to be influenced by the levels of the B-group vitamins and insulin secretion.

Serotonin has been shown to act as a mood stabiliser and its deficiency has been implicated in learning difficulties, reinforcement contingencies and in a number of affective disorders. Therefore a diet that significantly increases levels of serotonin in the brain may have an important role in the treatment of canine behaviour and training problems.

**Nutritional perspective and effects**

Appropriate nutrition requires that all nutrients, carbohydrates, lipids, proteins, minerals, vitamins and water are ingested in adequate amounts and in the correct proportions to the energy content of the food. This is essential for normal organ development and function, reproduction, repair of body tissues and combating stress and disease. The nutrient intake must also be adjusted for varied levels of activity and physical work.

Ingested protein is broken down into its component amino acids. It is well known that the amino acids tryptophan and tyrosine are converted to neurotransmitters in the mammalian brain. Tyrosine is converted to the catecholamine stimulants adrenaline, dopamine and noradrenaline; while tryptophan is converted to the indolamine serotonin.

Noradrenaline induces high states of arousal and has been implicated in the generation of aggression. Dopaminergic pathways in the brain are concentrated in the basal ganglia region and are involved in motor co-ordination, attention, reinforcement and reaction time. The indolamine, serotonin, was first discovered in 1948. Since then, a rather extensive network of serotonergic neurons has been identified in the mammalian brain, which originate within the raphe-nuclei region situated in the brain stem.

At most synapses, serotonin produces inhibitory postsynaptic potentials, and its behavioural effects are also generally inhibitory (Carlson, 1994). Serotonin plays a role in the regulation of mood, the control of sleep and arousal, the regulation of pain and in the control of eating. Low serotonin levels have also been implicated in alcoholism, obsessive compulsive disorders and other reward deficiency syndromes, such as impulsivity, violent behaviour, suicidality, anti-social behaviour and attention deficit hyperactivity disorder (Vander et al, 1994); (Linnoila & Virkkunen, 1992).

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It has been shown in humans and other species that certain amino acids directly influence brain activity and behaviour by enhancing or reducing the
rate of synthesis of various neurotransmitters (Figure 1). The ratio of the concentration of the large neutral amino acids – tryptophan (Figure 2), tyrosine, leucine, isoleucine, valine and phenylalanine – in the diet can significantly affect the biosynthesis of the groups of neurotransmitters known as the monoamines, which play a pivotal role in the regulation of arousal states.

Control and competition

The concentration of an amino acid in the diet or in the blood does not directly reflect its level in the brain. A complex group of blood-brain barrier mechanisms closely controls both the kinds of substances that enter the extracellular fluid of the brain and the rate at which they enter. Amino acids, amongst other important substrates, use an active transport mechanism, combining with transport proteins to cross the blood/brain barrier.

For amino acids, these carrier mechanisms are both size and charge specific. Within each carrier group, individual amino acids compete for uptake. Hence, an event such as meal ingestion can influence the level in the brain of a given amino acid by modifying its concentration in the blood and/or the blood concentration of other amino acids that compete with it for uptake. Therefore, the ratio of tyrosine or tryptophan to the sum of the other large neutral amino acids in the circulation will effectively control the amount of the amino acid taken across the blood-brain barrier.

The amount of tryptophan entering the brain depends primarily on the ratio of the plasma tryptophan concentration to the sum of the plasma concentrations of the other large neutral amino acids – leucine, isoleucine, valine, phenylalanine and tyrosine (Eastwood, 1997); (Growdon & Wurtman, 1976). This significant correlation between the serum levels of individual amino acids and their ratio to the sum of other transport competitors supports the theory that competition between tryptophan and other large neutral amino acids is very important and is a dominant determinant of tryptophan uptake into the brain (Vander et al, 1994).

Tryptophan in foods

Tryptophan is present in relatively low amounts in high protein foods compared to other large neutral amino acids, such as tyrosine. Therefore, when a meal that contains a high concentration of protein is ingested, tyrosine gains a competitive edge for entry into the brain. Conversely, following a high carbohydrate load, tryptophan enters the brain; although Fernstrom and Fernstrom (1965) state that brain tryptophan can only be raised by carbohydrate intake if the carbohydrate meal is given within two to three hours of protein ingestion.

Serotonin in the brain is synthesised from tryptophan; but, the rate-limiting step is hydroxylation of tryptophan to 5-hydroxytryptophan via tryptophan hydroxylase. This is then converted to serotonin by aromatic L-amino acid decarboxylase (Fernstrom, 1983). Tryptophan hydroxylase is a low affinity enzyme – a molecule of tryptophan and a molecule of the enzyme have no strong inclination to bind. Therefore, it is only when the concentration of tryptophan is much higher than normal that the enzyme can function at its maximum rate (Fernstrom & Wurtman, 1983).

Amongst their other various functions, the B-group vitamins maintain the functional integrity of the mammalian nervous system. The enzymes involved in serotonin synthesis are B₆ and riboflavin-dependent, as these act as co-factors, particularly in decarboxylation reactions (Growdon & Wurtman, 1976). As the B-group vitamins are water soluble, an adequate concentration needs to be provided in the diet on a daily basis.

Neurochemistry of learning

Animals have evolved to learn through reinforcing events (Gray, 1987). However, if the brain’s reinforcement mechanisms are impaired, then the ability to experience reinforcing events will be reduced and learning affected accordingly. In fact, if an individual has a biochemical inability to derive reward from ordinary everyday activities, then behavioural problems – such as addictive, compulsive or impulse control disorders – may result (Blum et al, 1996).

Dopamine is the primary neurotransmitter of reward in the limbic system, but at least three other neurotransmitters are known to be involved: serotonin, the enkephalins and gamma aminobutyric acid. In a normal individual, these neurotransmitters work together in a cascade of excitation or inhibition leading to a feeling of well-being, the ultimate reward (Blum & Kozlowski, 1990).

A disruption of these intracellular interactions results in anger, anxiety and other “negative feelings”, or in a craving for substances that alleviate these negative emotions. Prolonged stress can lead to a self-sustaining pattern of abnormal cravings in both animals and humans. Research on alcoholic rats (McBride et al, 1990) shows that the increase of supply of serotonin at the synapse will reduce craving for alcohol.

The biological substrates of reward are the basis for impulsive, compulsive and addictive disorders, comprising the reward deficiency syndrome. The reward circuitry for habit-forming behaviours is the same as that for natural rewards.

The reward cascade begins with the excitatory activity of serotonin releasing neurons in the hypothalamus. This then causes the release of the opioid peptide, met-enkephalin in the ventral tegmental area, which inhibits the activity of neurons that release the inhibitory neurotransmitter gamma amino butyric acid. The disinhibition of dopamine containing neurons in the ventral tegmental area allows them to release dopamine in the nucleus accumbens and in certain parts of the hippocampus, completing the cascade and mediating reinforcement effects.

Figure 2. A molecular structural model of the amino acid, tryptophan. (Image credit: Marina Vladivostok)
Learning involves the strengthening of the connections between neural circuits that detect a stimulus and neural circuits that produce a particular response. An inability to experience reinforcing events – be they positive or negative – will lead to reduced learning capabilities and associated behaviour problems.

A combination of genetic and environmental factors can affect an animal’s ability to cope with novel situations and learning tasks (Baumeister et al, 1994). The secretion of hormones, such as the corticosteroids, through dysregulation of the hypothalamic pituitary adrenal axis, in response to prolonged stress, can reduce brain levels of serotonin (Koob & LeMoal, 1997). This explains the many abnormal behaviour patterns sometimes seen in dogs in rescue shelters (Fisher, 1990).

Serotonin, gamma amino butyric acid, glutamate, dopamine and opioid systems have been shown to be involved in mediating positive reinforcement systems (Koob & LeMoal, 1997), and a deficiency in the reward cascade causing lowered levels of serotonin can lead to negative states, such as depressed mood, dysphoria, irritability, and impulsive behaviour via a reduction of the behavioural inhibition system during learning.

**Emotion versus mood**

All human and animal behaviour is influenced by moods and emotions, both of which affect each other (Panksepp, 2005).

Emotions involve a relationship between the individual and an explicit cause/object/event. Emotions are acute, and short-lived, lasting milliseconds, or minutes at most. The cause that elicits an emotion (the stimulus) can be anything from an event in the environment to individual thoughts and memories (Ekman, 1994). In contrast, moods last for hours or even for several days (Beedie, 2005).

Moods are not directed at a particular object or cause, but rather are a culmination of similar experiences. Consequently, we are generally unable to specify the cause of a particular mood (Ekman, 1994). Mood is the background feeling of the day, how the animal feels and behaves generally when not displaying the problem behaviour. A depressed dog will be much more difficult to motivate and an overexcited dog is unlikely to be able learn to focus and be calm when meeting people.

Behaviour problems are not diseases. Successful treatment depends upon accurate assessments of how the animal feels - fearful, angry, for example – at the time the problem behaviour occurs and the animal’s general mood state.

**Assessment tools**

When describing emotional states, the term often used is **Anxiety/agitated/unable to settle** before weeks 1, 2, and 3.

**Reactivity/low impulse control** before weeks 1, 2, and 3.

**Table 1.** Form for the assessment of emotional state/response within a kennelled environment

<table>
<thead>
<tr>
<th>Anxiety/agitated/ Unable to settle</th>
<th>Calm/relaxed</th>
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</thead>
<tbody>
<tr>
<td>Before</td>
<td></td>
</tr>
<tr>
<td>Week 1</td>
<td></td>
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<tr>
<td>Week 2</td>
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<tr>
<td>Week 3</td>
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<table>
<thead>
<tr>
<th>Reactivity/low impulse control</th>
<th>Composed/responsive</th>
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</thead>
<tbody>
<tr>
<td>Before</td>
<td></td>
</tr>
<tr>
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<td></td>
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<tr>
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<td></td>
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<tr>
<td>Week 3</td>
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</tr>
</tbody>
</table>

10 = an intense negative emotional state and low positive emotional state; 1 = an intense positive emotional state and low negative emotional state.

Figure 3. Using the PANAS model, emotional states can be plotted on a two-dimensional grid.

**Table 1.** Form for the assessment of emotional state/response within a kennelled environment
‘affect’, meaning the experience of feeling or emotion. In 1988, Watson et al. (1988) published a paper introducing the Positive and Negative Affect Schedule (PANAS), based on the idea that positive and negative affect should be separately tracked because they vary independently.

Using the PANAS model, emotional states can be plotted on a two-dimensional grid. On the x-axis “pleasantness/unpleasantness,” on the y-axis “arousal,” or “activation” and emotional states are placed around these axes (Figure 3).

Active-pleasant emotional states are those of excitement and pleasurable engagement, while misery and lethargy are the opposite passive-unpleasant states. The active-unpleasant emotional states are those of distress or irritation and non-pleasurable engagement and include anxiety, fear, and terror as well as irritability, anger and rage. Passive-pleasant states are those of calmness and contentment.

Inability to express or engage in innate motor patterns may result in a lowered mood state, provoking intense emotional responses to various stimuli. Irrelevant behaviour patterns, displacement activities or coping strategies, such as scratching or barking, may be exhibited in response to the frustration of intermittent reinforcement (Fisher, 1990).

Inadequate or ineffective reinforcement may elicit adjunctive behaviours, such as drinking or redirected aggression (Blum et al., 1996) or a hyperactivity state caused by the arousal of the noradrenergic pathways. Low levels of serotonin have been associated with high locomotor responses, especially in response to novel situations such as change in surroundings in a rescue shelter.

The assessment of emotional state/response can provide an accurate measure of behavioural response within kennel environments. Scores are given to all relevant emotional states to provide a validated scale of assessment. Scores of 1 to 10 indicate the observer’s objective evaluation of the intensity of the dog’s emotional state (Table 1).

**Behavioural evidence**

The author has formulated a serotonin-enhancing diet* that uses insulin – secreted in response to carbohydrate ingestion – to regulate plasma glucose levels and divert other large neutral amino acids to peripheral skeletal tissues, where they are involved in energetic and immune system pathways; thereby enabling tryptophan to gain a competitive edge across the blood brain barrier.

A feeding study was carried out at Wood Green, The Animals Charity, involving 38 dogs of various breeds/type. Their average time in kennels was 58 days. Inclusion into the study required the dogs to be in good health, with no history of dietary intolerance, not receiving any veterinary treatment or medication, or any remedial behaviour therapy.

Two aspects of common problem behaviour within a kennel environment were studied:

- Group 1 (24 dogs) anxiety/agitated agitation/inability to settle versus calm/relaxed
- Group 2 (14 dogs) reactivity/low impulse control versus composed/responsive

Behaviour was assessed prior to entering the study (week 0), and at weeks 1, 2 and 3 of the study period.
Reactivity/low impulse control

Prior to diet
After three weeks on diet

Composed/responsive

Prior to diet
After three weeks on diet


Although not one of the outcome measures, several dogs were able to be moved into the rehoming kennels part way through the trial.

Of the dogs in Group 1, Dog 23 made no improvement on the diet. Of the remaining 23 dogs, there was an average 53 per cent reduction in anxiety and agitation with a comparable 61 per cent improvement in calm/relaxed behaviour (Figures 4 & 5).

In all 14 dogs in Group 2, there was an average 55 per cent reduction in reactivity with a comparable 59 per cent improvement in composed/responsive behaviour (Figures 6 & 7).

Conclusions

Rescue kennels are stressful environments for most dogs. These preliminary results suggest that a serotonin-enhancing diet can have a positive effect on dogs’ mood state and emotional responses, and their ability to respond to training. This, in turn, can have a positive effect on the welfare and management of dogs in rescue shelters and their successful rehoming.

References


