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## Caffeine use in the 21st Century: Considerations for Public Health

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### Abstract

Caffeine has been consumed for thousands of years, with the primary sources originally being tea leaves and coffee beans. However, over the past 120 years new caffeinated foods and beverages have been developed and marketed worldwide, which has led to an increase in caffeine consumption in both children and adults. Concomitant with the rise in caffeine consumption has been a rise in the number of caffeine-induced incidents leading to emergency room visits or calls to poison centres. The reasons for the increases in caffeine consumption and related health concerns are likely to be multi-factorial and include aspects such as the wide range of caffeine sources available, the variability in caffeine content between and within products, lack of knowledge by the consumer, compounded by the wide variety of reasons for its consumption. In addition, with the advent of caffeinated products such as energy drinks and ready-to-drink beverages which frequently contain high levels of sugar, alcohol or other stimulatory compounds, adjuvant effects are possible. Life in the 21st century is faster and more competitive than it has ever been, and lifestyles are constantly changing to reflect that. Although consumption of increasingly accessible caffeinated beverages may aid in achieving life's goals, the question remains as to how this increased consumption may impact on health, particularly in the long term. The aim of this review is to explore the above issues in an effort to raise awareness and stimulate discussion as to future public health concerns.

**Keywords:** Caffeine Consumption; Metabolism; Pharmacological Aid; Energy Drinks

### Introduction

#### Historical consumption

Based on Chinese legend, historians believe that caffeine was first consumed in the form of tea as far back as 2737BC [1]. Tea continued to be consumed primarily for medicinal purposes (not necessarily those deriving from caffeine) until the Tang dynasty (618-906AD), when its popularity as a beverage grew. Consumption of caffeine from coffee beans is thought to have originated in Ethiopia in the 9th century with the Galla tribe consuming balls comprised of animal fat and ground coffee cherries for energy during battles or long marches. A popular legend, also originating from Ethiopia around the same time, is that of a goat herder, who, after noting that his goats had more energy after eating wild coffee berries, tried the berries himself, and after experiencing the same effect passed the information on to the local monastery, from where word spread. Coffee as a beverage was not invented until around 1000AD, and the world's first coffee shop was opened in 1475 in Constantinople. Coffee consumption slowly spread around the world over the next several hundred years and burgeoned to such an extent that worldwide coffee consumption is thought to be in the order of 500 billion cups per year [2].

Three caffeinated soft drinks became available during the late 1800s, with the development of Dr Pepper in the 1880's, Coca-Cola in 1886 and Pepsi in 1893. Coca-Cola was originally invented by pharmacist John Pemberton as an alternative cure for morphine addiction, from which he himself suffered. Pemberton died destitute, after selling the formula to Asa Candler (founder of the Coca-Cola company), who aggressively marketed the product making it one of the USA's most popular drink fountain products by the late 1890's. Pepsi, originally known as Brad's Drink, until being renamed Pepsi-Cola (for the pepsin and kola nuts which it contained) in 1898, was developed and sold at a drug store by Caleb Bradham, who sought to make a product that would aid digestion and boost energy.

The caffeine-containing energy drink Red Bull debuted in 1997 and since then more than 500 new energy drinks have been marketed around the world [3]. These drinks vary considerably in their caffeine content, but generally contain an amount equivalent to consuming between one and three cups of coffee [4]. The energy drink market continues to be dominated by Red Bull, with about 43% of the approximately US$50 billion a year global market [5] and with worldwide energy drink consumption having doubled between 2006 and 2012 [6].

**Consumption trends**

Not surprisingly, trends in the major sources of caffeine in the diet have changed over the past 100 or more years, no doubt in response to broader availability as well as the development of a wider range of caffeine-containing products. Until recently, coffee, soft drinks and tea have been the major dietary sources of caffeine [7], with the relative proportions of these sources changing according to age group, with coffee being the major dietary contributor in adults, and soft drinks in children and teens [7].

Caffeine consumption trends are changing and energy drinks are now a common source of dietary caffeine, particularly in the targeted 18-35 age-group [3]. In US high school students, 5% are reported to drink one or more energy drinks per day [8]. Furthermore, 51% of college students consumed at least one energy drink per month, and 73-86% of these consumed energy drinks 1-4 days a month. Consumption of multiple energy drinks in a day was popular and, of the energy drink consumers, 49% reported that they drank at least 3 energy drinks per session, often accompanied by alcohol while partying [3]. In Poland, energy drink consumption has been reported to be similar between junior high school (15 year olds) and university students (23 year olds)(48% and 53%) [9], but with a higher prevalence in males than females as has been found in a number of studies around the world [9-11]. A recent study, carried out in US Army personnel [10], showed that although coffee was the major source of caffeine in older soldiers, energy drinks and soft drinks were the major sources in the youngest age group (18-24 years). Moreover, 44.8% of surveyed US Service Members deployed in Afghanistan [4] reported consuming at least one energy drink per day, with 13.9% having three or more per day. The increased availability of caffeinated sodas and energy drinks, along with the targeted marketing of these products to young people, has resulted in large increases in caffeine consumption in children and adolescents; with reported increases of around 70% occurring from 1970-2000 in the USA [11,12]. Some studies report that caffeine consumption in this age group (2-22 years) is continuing to increase [11-14] while others report that overall intake is similar, but the sources are changing [15].

Given the obesity epidemic occurring worldwide, the fact that caffeinated sodas and energy drinks are frequently high in sugar and nutrient poor is a major concern. This concern is supported by an Australian study which has shown that children (2-16 years) who consumed caffeinated sodas and energy drinks also had a higher caloric intake than their non-caffeine consuming counterparts [16]. The consumption of caffeinated beverages by children is of concern worldwide and a number of countries are suggesting interventional mechanisms for lowering intake [16] and also greater regulation concerning the use of caffeine as an additive.

**Variability of caffeine content in different beverages and products**

The beans, leaves and fruits of more than 60 plants contain caffeine (Figure 1A) at varying levels [17,18]. Coffee beans (Fig 1B), tea leaves, kola nuts and cocoa beans are probably the mostly widely recognised naturally occurring caffeine sources. The caffeine levels differ due to plant variety and environmental influences as well as storage, processing and brewing methods [17].

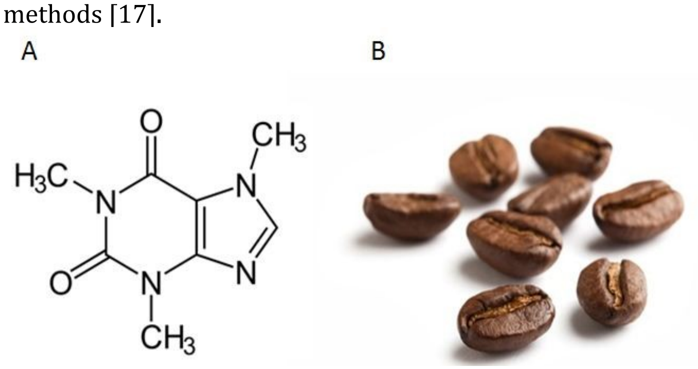


**Figure 1.** Structure of caffeine (A) and photo of coffee beans (B) the most common source of caffeine.

Caffeine levels in coffee are approximately 50-70% higher than in tea [19], and also vary more [17], with the caffeine content of coffee ranging from 60-200 mg per serving of ready-to-drink coffee, 40-180 mg/serve of filtered coffee and 30-120 mg/serve of instant coffee [20]. A snap-shot study of the caffeine content of a single shot espresso from 20 commercial outlets in Glasgow showed a six-fold variation in caffeine content (51-322 mg/serving) with a four-fold variation in volume [21]. A similar study in Australia [22] also found considerable variation in both espressos purchased from cafe chains in different locations (49-214 mg/serving) and coffee-flavoured milks obtained from grocery stores (33-197 mg/serving). Both sets of authors [21,22] quite rightly point out that such variation, accompanied by the lack of information about the caffeine content of drinks being served, could put individuals at increased risk of the effects of caffeine toxicity. This is particularly true as the consumer cannot rely on the volume being proportional to caffeine content, as demonstrated by espressos produced by three different sources, each contained 140 mg of caffeine, but had volumes of 26, 45 and 70 mL, respectively [21]. Energy drinks contain varying amounts of caffeine according to brand; typically the caffeine content of 1-3 cups of coffee [4], and often including additional ingredients also aimed to enhance mental alertness and physical energy, such as taurine, sugars and amino acids.

A number of medications marketed for the relief of headache include caffeine as a key ingredient. The adjuvant effect of caffeine in these products is now well documented with the inclusion of caffeine in combination with acetylsalicylic acid and paracetamol being significantly more effective than either component alone or in the absence of caffeine [23]. Caffeine increases the analgesic potency of acetylsalicylic acid by around 40% and decreases the plasma clearance of acetaminophen [24]. The doses of caffeine reported to have an adjuvant effect are generally greater than 50 mg [23,25], which is a dose achievable from a single cup of caffeinated coffee in most cases. Over 1000 prescription drugs available in the USA have been reported to contain caffeine [17]; however, the levels tend to be lower and less variable (30-100 mg/tablet) than those found in over-the-counter medications (15-200 mg/tablet).

**Metabolism and effect of genetics**

Caffeine is considered to be 100% absorbed [25], and the rapid absorption rate from the gastrointestinal tract is thought to be dependent on the gastric-emptying rate (90% cleared within 20 minutes). For healthy adults, the peak plasma concentration of caffeine occurs 1-1.5 hours after ingestion with a half-life of 2.5-10 hours, although both high intakes and repeated caffeine ingestion result in reduced clearance and hence an extended half-life for both caffeine and its metabolites [26]. Ethnicity also impacts caffeine clearance rates with Asian and African populations metabolising caffeine at a slower rate than Caucasians [27]. In addition, in pregnant women, women taking oral contraceptives [28], the developing fetus, young children and people with impaired liver function the half-life is increased by up to 30 hours [21], while it is shortened in smokers [20]. Physical activity does not appear to affect the pharmacokinetics of caffeine metabolism [26].

Caffeine is metabolised by cytochrome P-450 enzymes (*CYP*), but its effects are primarily mediated via antagonism of the adenosine receptors (*ADORA*). The *CYP* genes largely determine the rate of caffeine metabolism and therefore how long caffeine will remain in the body, while the *ADORA* polymorphisms influence/impact the nature and extent of various physiological effects. Hence these genes play key roles in both acute and chronic responses to caffeine ingestion.

Caffeine is primarily metabolised by cytochrome P-450 enzymes in the liver at a linear rate when consumed at lower levels (70-100 mg); however, at higher levels (250-500 mg) clearance is significantly slower and potentially non-linear. The gene *CYP1A2* codes for the enzyme predominantly responsible for the demethylation of caffeine to its three primary biologically active metabolites: 3,7 dimethylaxanthine (theobromine, 12%), 1,7 dimethylaxanthine (paraxanthine, 84%) 1,3 dimethylaxanthine (theophylline, 4%) [29], with about 5-10% excreted unchanged [19].

Caffeine clearance rates vary by as much as 40-fold within and between individuals [27]. This variation is primarily genetic (72.5%), with the remainder (27.5%) being due to environmental factors [30]. A single nucleotide polymorphism (SNP) rs762551A/C has been shown to result in alteration of cytochrome P-450 1A2 enzyme activity [31]. Since this polymorphism is located in the non-coding region of *CYP1A2*, it has been suggested that this polymorphism causes changes to the levels of expression of the *CYP1A2* protein by affecting binding of regulatory proteins to the surrounding sequence [31]. Therefore, homozygotes for the wild-type A allele, represent a highly inducible genotype and are fast caffeine metabolisers; while homozygotes for the variant allele C and heterozygotes (C/A) are slow metabolisers [31]. There appears to be some variation in expression of the different genotypes according to ethnicity, although data remains limited. A study in 236 Caucasians from Germany yielded ratios of 46% A/A, 44% C/A, 10% C/C [28], while a study of 110 Italian males gave ratios of 34% A/A, 64% C/A, 2% C/C [32].

Homozygous slow caffeine metabolizers (C/C genotype) are at greater risk of adverse effects due to caffeine consumption, including an increased risk of non-fatal myocardial infarction (MI) and a caffeine-induced increase in blood pressure [33,34]. Elevated levels of the pro-inflammatory cytokines TNF-α and IL-6 have been detected in patients with congestive heart failure, and these cytokines downregulate *CYP* enzyme activity, possibly causing impairment of important *CYP*-mediated drug metabolism including cardiovascular medications [35]. This may go part way to explain why cardiac patients with the slow *CYP1A2* genotype are at increased risk of MI [33].

The biological effects of caffeine consumption are brought about by several mechanisms, but the primary mode of action is as a potent antagonist of the adenosine receptors. There are four different subtypes of adenosine receptors ($A_1$, $A_{2A}$, $A_{2B}$, $A_3$), which are expressed in most tissues of the body. When activated by adenosine these receptors generate second messengers (e.g. cAMP) that modulate a variety of cellular responses.

Caffeine also inhibits phosphodiesterases, promotes intracellular calcium release, and interferes with GABA-A (gamma-aminobutyric acid) receptors [36]. Hence, the potential effects of caffeine consumption are diverse and complex [26,37]. In humans, the main effects that have been detected following caffeine consumption are those to the cardiovascular and central nervous systems, as well as changes to carbohydrate metabolism, inflammatory mechanisms, metabolic rate and diuresis [37].

Polymorphisms (rs5751876 (1976 C/T)) in the adenosine *A2A* receptor gene (*ADORA2A*) have been associated with a number of effects following caffeine consumption. The 1976 T/T genotype has been associated with caffeine-induced anxiety [38] (also linked with rs35320474, 2592T/- [39]), panic disorders [40], increased startle reflexes, particularly in females [41] and increased systolic blood pressure [32], possibly through adrenaline secretion which has been shown to increase following caffeine ingestion [32, 42]. Polymorphisms in the α2-adrenergic receptors also contribute towards the variability of cardiovascular responses to caffeine [32]. The 1976 C/C polymorphism is associated with reduced sleep quality and changes in the electrical activity of the brain during sleep in caffeine sensitive individuals to that resembling insomniacs [43].

Since people are likely to adapt their caffeine consumption habits according to their own personal consumption experiences (positive or negative), it is not surprising that there are associations between certain genotypes affecting caffeine metabolism and caffeine consumption habits. Individuals with the *ADORA2A* T/T genotype, who tend to experience negative effects following caffeine ingestion, consume significantly less caffeine than carriers of the C allele [44]. A recent study [45], has identified 8 loci which are associated with caffeine consumption, most of which are in or near genes associated with the pharmacokinetics or pharmacodynamics of caffeine.

**Effects of caffeine consumption and reasons for consumption**

Caffeine consumption has been reported to elicit a wide variety of effects, some of which are summarised in Table 1. The most widely recognised and researched effects of caffeine ingestion (relative to placebo) include improved alertness, faster thought flow, faster reaction times, improved memory, enhanced cognitive performance, changes in mood, increased periods of wakefulness and diminished sleep latency, reduced fatigue, and various sporting and exercise-related effects (see Table 1 for references). However, caffeine consumption has also been linked with decreased risk of depression and Parkinson's disease, but increased risk of headaches (Table 1).

Although much of the world now has an embedded 'café culture', where consumption of caffeinated beverages such as hot or iced coffee or tea are very much a part of social activities, changing lifestyles are also influencing caffeine consumption habits. The competitive atmosphere of work, study and sporting activities is influencing people to take caffeine in its various forms in order to improve their performance. Many people now cite the stimulatory effects of caffeine as their primary reason for consumption. In addition, users often take and associate different caffeinated products with different purposes. For example, when listing circumstances surrounding consumption of caffeine containing beverages, university students in Poland listed ingestion of coffee (89%) while studying more frequently than energy drinks (50%), with consumption of coffee (75%) and colas (78%) preferred during social occasions [9]. In the same study, younger students (15 years) also favoured coffee consumption while studying (55%), but primarily drank colas during social occasions (65%), and unlike the older age group drank energy drinks during and after physical exertion (60%), whereas the older age group drank colas (59%) for this purpose.

Advertising has also created a strong link between consumption of energy drinks and various high adrenalin sports and activities; the digital age has created a positive association between number of digital devices owned and caffeine intake, as people strive to stay awake longer in order to play computer games and watch movies online [46].

While under certain circumstances the stimulatory benefits of caffeine consumption can be considered beneficial, under others they can be detrimental (e.g. sleeplessness), and consumption of caffeine in excess can result in a variety of unpleasant symptoms such as anxiety, nervousness, mood changes, state of excitement, nausea, palpitations, tremors, and a racing mind [19,47] and in extreme circumstances lead to liver damage, kidney failure, respiratory disorders, seizures, hypertension, heart failure, myocardial infarction and even death [48]. The dose responses causing unpleasant side effects vary hugely; in some people the caffeine from less than a single cup of coffee can elicit detrimental effects, whereas with others the consumption of 10 times as much caffeine may still not result in unpleasant effects. Some of this diversity in responses is due to tolerance brought about by habitual caffeine ingestion [49], which can occur after only four or five days of caffeine consumption, however, tolerance is not observed in all coffee drinkers. It has been suggested that the synthesis of additional adenosine receptors in response to chronic caffeine ingestion is responsible for habituation [19]. Genetic variation is also thought to contribute significantly to the variation in individual responses to caffeine ingestion [49].

Caffeine is viewed as a reinforcer; a substance which increases the likelihood of further ingestion of the same substance [50]. In this regard caffeine has a key role in developing flavour preferences, promoting continued caffeine consumption and also avoidance of caffeine withdrawal symptoms which include headaches, fatigue, poor concentration, insomnia, drowsiness,

**Table 1.** Summary of the effects of caffeine consumption

| Parameter | Subject/context | Effects of Caffeine Consumption | Refs |
|---|---|---|---|
| Depression | 50,739 Women, USA | ↓ risk with ↑ intake | 62 |
| | 2,232 Men, Finland | ↓ risk with ↑ intake | 63 |
| Suicide | 86,626 Women, USA | ↓ risk with ↑ intake | 64 |
| | 128,934 Men and Women, USA | ↓ risk with ↑ intake | 65 |
| | 43,166 Men and Women, Finland | J-shaped curve; Heavy drinkers 58% ↑ risk of suicide than moderate drinkers | 66 |
| Osteoporosis | 190 Women, USA | ↑ Calcium loss with ↑ intake | 67 |
| Cardiovascular disease | 93,676 Women (postmenopausal), USA | No association with sudden cardiac death | 68 |
| Asthma | 72,284 Men and Women over age of 15years, Italy | ↓ asthma with ↑ intake<br>↓ respiratory muscle fatigue | 69 |
| Parkinson's disease | Meta-analysis of 16 studies Worldwide | ↓ risk with ↑ intake | 70 |
| Sleep | 988 Army and Marine service members, USA | ↓ sleep with ↑ intake energy drinks | 4 |
| Headaches | 1,260 14-20 years, Germany | ↑ risk with ↑ intake | 71 |
| | 803 Men and Women, USA | ↑ risk with chronic caffeine<br>↑ risk of migraine with ↑ intake | 72 |
| | 22 Subjects | ↑ risk during caffeine withdrawal | 73 |
| | 1,741 Men and Women, Denmark | ↑ risk during caffeine withdrawal | 74 |
| Pregnancy and obesity | 1,986 Women/child pairs (pregnant during the 1960's), USA | No association of ↑ risk of childhood obesity in children up to 7 years | 75 |
| | 615 Women (pregnant during the 1990's) | Consumption of ≥150 mg caffeine per day↑ risk of persistent obesity in children up to age 15 years | 76 |
| Cognitive function | 9,003 Men and Women, UK | ↑ cognitive performance with ↑ intake | 77 |
| Skill performance | 12 Men soccer players, New Zealand | ↑ passing accuracy and ↑ jump performance | 58 |
| | 15 Men soccer players, New Zealand | ↑ passing accuracy and ↑ jump performance<br>↓ fatigue | 59 |
| Perceptual responses | 10 Women team-games players, New Zealand | ↑ ratings of pleasure and arousal during exercise | 61 |
| | 15 Men soccer players, New Zealand | ↑ ratings of pleasure | 59 |

**Table 1. Cont**

| | | | |
|---|---|---|---|
| Ergogenic effects | Review of 28 studies Worldwide | ↑ ergogenic effects of caffeine ingestion on both endurance and short-duration high-intensity exercise (sprint) | 78 |
| | 10 Men, Canada | ↑ time to exhaustion by maintaining force | 79 |
| | 10 Men, Canada | No ergogenic benefit in some individuals | 79 |
| | 14 Men trained runners, UK | | 80 |
| | 35 Men cyclists, USA | Fast caffeine metabolisers (A/A genotype) displayed ↑ ergogenic effects following caffeine ingestion than did slow metabolisers (C/A, C/C) | 81 |

gastrointestinal upsets, joint pain and dysphoric mood [36,43]. The reinforcing nature of caffeine leads to the condition known as caffeine dependence (addiction), which is now recognised by the World Health Organisation as a clinical disorder, with individuals being unable to reduce their caffeine intake in spite of the detrimental health effects (physical or psychological) associated with its continued use [50].

Both the possible short and long-term effects of increased caffeine consumption in children are of great concern. Some short-term studies are now showing that in children (14-15 years) caffeine consumption is correlated with increased daytime sleepiness, increased anger [51] and inversely correlated with academic achievement [52]. Caffeine consumption in 15-16 year olds is also strongly correlated with violent behaviour and behavioural disorders [53] with the relationship being stronger for girls. Further studies are clearly needed in this area, along with studies investigating if children consuming caffeine on a regular basis suffer from any long-term effects.

**Excess intake**

Worldwide there has been a rise in the number of incidents of caffeine-induced symptoms reported within emergency departments, hospitals and poison centres. In particular there has been an increase in caffeine-related toxicological events and deaths, in the children through to young-adult age group, with 46% of total events occurring in under-19 year olds [48,54]. In the US there was a doubling of Emergency Department visits due to energy drink consumption over the 2007-2011 period [55].There has also been an increase in the reported cases of caffeine poisoning in NZ, with approximately one quarter due to consumption of energy drinks [56].

A number of factors are likely to have contributed to this rise in detrimental effects following caffeine consumption, including the accessibility of a wide range of caffeine sources, and the variability in caffeine content between and within products as previously mentioned. Another potential contributing factor is lack of knowledge by the consumer, because although people are generally aware that coffee, tea and cola beverages contain caffeine, they are frequently not cognisant of the variability of caffeine content in coffee and energy drinks, or the presence of caffeine in products such as non-cola soft drinks, ice-cream, chocolate and yoghurt, and in over-the-counter medications such as cold and flu remedies, weight-loss products and analgesics (Rowe, unpublished MSc thesis). In addition, caffeine effects are often exacerbated by co-ingestion with other substances (e.g. recreational drugs and alcohol), and even moderate caffeine consumption can impact on the efficacy of prescribed medications [57], a fact rarely understood by the consumer.

Another factor which may hinder consumer knowledge and understanding is that in some countries manufacturers of products which naturally contain caffeine are not required to quantify the levels [22], and therefore it is possible that consumers may inadvertently consume large amounts of caffeine from products such as coffee-flavoured milk. The levels of caffeine in both foods and drugs also appear to be altered by manufacturers as they see fit, which adds to the difficulty for those individuals attempting to control their caffeine intake [19]. In addition, the recent trend of adding caffeine to a range of products which traditionally do not contain caffeine – such as instant oatmeal, jelly beans, chewing gum and marshmallows – has the potential to cause harm. Several of these items are attractive to children and young people and, although considered treat foods, people frequently over eat them. Also, once outside of their original packaging the fact that the product contains caffeine becomes 'hidden' and this could result in inadvertent and/or over consumption of caffeine with potentially dangerous ramifications.

**Caffeine intake now...**

Improved health care has contributed significantly to our ability to live longer, however, our lifestyle choices are now threatening to seriously impact on the quality of that increased life span. Levels of physical activity are reducing across all age groups, and this combined with poor food choices as well as aging has led to increases in chronic diseases such as obesity, diabetes, cancer and heart disease. Other key hallmarks of aging include declining strength, mobility and cognitive function and increases in dementia including Alzheimer's disease. Hence, while we may be living longer, we have a poorer quality of health, particularly in the latter stages of life.

As the world's population ages it is important to try to improve the quality of life of the elderly, not only for personal well-being but also to reduce health care costs. With its ability to enhance cognitive function, skill performance [58,59] and improve strength [60] and enhance perceptual/mood responses during exercise [61] caffeine could be a useful tool for improving these factors in some elderly. More research is needed to investigate the efficacy of caffeine consumption is improving quality of life in the elderly.

The field of nutrigenomics could be key in providing tailored nutritional information for improving health in the future. In the meantime, lifestyle genetic testing is gaining popularity, and although there are ethical considerations and possible insurance issues, such testing has the potential to provide useful information. From a caffeine perspective, knowledge of both *CYP* and *ADORA2A* genotypes may be useful information for those who should avoid caffeine due to negative effects, and also for people interested in whether they are likely to experience performance-enhancing effects from caffeine consumption. As more becomes known regarding the impact of specific genes on health and the links between genes and caffeine consumption effects, the consumer will have more knowledge on which to base their own consumption practices.

**...and in the Future?**

There is still much to be learnt about how genetics impacts on the efficacy of caffeine's myriad of effects, so all future studies investigating the effects of caffeine should incorporate a genetic analysis element. Ultimately, such knowledge should lead to a tailoring of recommendations for caffeine ingestion for individuals, for specific purposes, for example, an athlete might be recommended to ingest a certain dose of caffeine for sporting performance, but a different dose for cognitive function.

Considerably more research needs to be conducted on the effects of caffeine consumption in a range of populations such as the elderly, and children in different circumstances. Investigations of how the effects of caffeine consumption may change when taken in conjunction with other compounds commonly found in energy drinks (e.g. guarana, taurine) and RTDs (alcohol) are also needed. In addition, alternatives to caffeine are needed for those of whom caffeine intake is contraindicated.

**Concluding Remarks**

Undoubtedly people will continue to consume caffeine in its many forms and for a variety of reasons. There does appear to be potential for using caffeine as a tool to improve performance (e.g. cognitive function), quality of life (e.g. improve muscle function in the elderly) and perhaps prevent disease (e.g. Parkinson's), although any gain needs to be balanced against the possibility of detrimental effects, particularly in vulnerable individuals and children. Clearly there are many questions that remain to be answered, and more research is required, for example investigating the effects of interactions between caffeine and compounds such as alcohol, guarana, taurine, ginseng, ephedrine, and seeking alternatives to caffeine. However, some changes are achievable in the short term which have the potential to deliver direct economic benefits to communities at large by reducing health care costs, and to individual consumers. These changes include better labelling of caffeine-containing products and better education of the general public with regards the products that contain caffeine, their levels of caffeine and the variability of the caffeine content. Being armed with this information will mean the consumer is empowered to take ownership of their own health and performance by making educated choices with regards caffeine consumption while ameliorating risk.

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