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The concept of well-being: relevance to nutrition research

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The aim of this paper is to discuss issues that fall within the general concept of well-being, with special emphasis on approaches that have been used in studies of nutrition and behaviour. Following this, two specific studies are described in detail, the first examining high-fibre breakfast cereals and the second investigating effects of inulin. Studies of nutrition and well-being can be categorised in a number of ways. One method involves examining acute effects of nutrition on mood and cognitive functioning. Another method has been to examine cross-sectional associations between dietary habits and questionnaire measures of reported health. Examples are given showing that regular consumption of a high-fibre diet is associated with better-reported physical and mental health. The problem with such correlational studies is that it is impossible to infer causality. Intervention studies are necessary to achieve this and some examples of this approach are given. In the first study reported here, we examined whether consumption of high-fibre breakfast cereal led to an increase in energy. Such an effect was observed and plausible biological mechanisms underlying such results are described. A similar methodology has recently been used to examine the effects of inulin. In this case the results showed no negative side-effects of taking inulin but there were no beneficial effects of inulin on measures of well-being (both subjective reports and objective measures). Possible reasons for these effects are discussed.

Well-being: Fibre: Inulin

The concept of well-being has become increasingly important since the acknowledgement that there is more to health than the absence of disease. In some areas well-being has been replaced by ‘quality of life’ or some other term that relates to the ability to function well (both physically and mentally) and to have a positive mood state. In the area of nutrition the term ‘functional food’ is widely used and this refers not only to the beneficial effects related to chronic disease but also to potential improved well-being. The next section briefly summarises some approaches we have adopted to study the topic.

Effects of food and drink on performance and mood

Initial interest in this area came from studies of the effects of lunch on alertness and the ability to sustain attention. Early research demonstrated that alertness drops after consumption of lunch and we are less able to sustain attention at that time (Smith & Miles, 1986*a*,*b*). However, consumption of caffeine removed this effect (Smith *et al.* 1990) and further research has shown that caffeinated drinks remove the negative effects of other low alertness states (e.g. working at night – Smith *et al.* 1993*a*; the common cold – Smith *et al.* 1997*a*). Similar results have been obtained in a number of other laboratories (see Lieberman, 1992; Fredholm *et al.* 1999, for reviews).

Consumption of breakfast has been associated with a more positive mood and better memory for lists of words (Smith *et al.* 1993*b*, 1994). This has been interpreted in terms of a beneficial effect of glucose on a brain deprived of glucose by the nighttime fast. Glucose may have other benefits and we have found that it improves simulated driving performance (Smith & Rich, 1998). Again, other laboratories have also demonstrated beneficial effects of breakfast consumption (e.g. Benton & Sargent, 1992).

The above effects reflect the acute benefits of consuming food and drink. Other studies have examined the longer-term effects of regular consumption patterns. For example, a number of studies show that consumption of breakfast, especially breakfast cereal, is associated with better physical and mental health (Smith, 1998, 1999, 2003). Similarly, the frequency and severity of minor illnesses may be reduced in those who regularly consume breakfast (Smith & Rees, 2000). In a large-scale secondary analysis of a representative community sample (Smith *et al.* 2000), we have found that breakfast cereal consumption is related to subjective health in a dose-related function and that digestive disorders such as constipation are associated with mental health problems. It is difficult to imply causality from these cross-sectional studies but they provide a good reason for conducting intervention studies aimed at altering the digestive process to subsequently change well-being. The next section outlines our first study on this topic (Smith *et al.* 2001).

An investigation of the effects of fibre in breakfast cereal on subjective reports of energy and mood

Previous research shows that digestive disorders are a major cause of morbidity. Dietary fibre is important in regulating digestive functioning and wheat bran is an excellent source of fibre. Bowel dysfunction is also associated with mental

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health problems, with causality being bi-directional. The study reported here (Smith *et al.* 2001) examined these associations and then manipulated the fibre content of breakfast cereal and examined changes in digestion and reports of health and well-being. A community sample of 139 volunteers completed the 4-week study (2 weeks normal breakfast, 2 weeks study cereals).

The cross-sectional analyses showed that high fibre intake was associated with significantly better reported physical and mental health. Similarly, digestive problems were significantly associated with impaired health and well-being, with the profile of effects depending on the symptoms reported. The intervention study successfully manipulated fibre intake. The consumption of both All Bran and Bran Flakes led to a significant change in bowel functioning (more digestive problems in the first week, fewer in the second) and significantly increased energy (reduced fatigue). These effects on fatigue were consistent over time. The present results suggest that increased dietary fibre from wheat bran cereals reduces fatigue. This effect does not depend on the removal of symptoms of bowel dysfunction.

Possible mechanisms

Fibre is fermented to SCFA by gut flora. Acetate goes to muscle and ATP is generated. Gut fermentation and subsequent use of SCFA contribute significantly to a person's energy requirements. This explanation plausibly accounts for the rapid effect of fibre and the magnitude of the effect. The second possible mechanism is detoxification. Clostridia are known to form neurotoxins and these come from protein metabolism not from carbohydrate or fibre. Fibre stimulates benign flora (bifidobacteria, lactobacilli) that cannot make toxins. This process is slow compared to the fermentation effects and could possibly explain the greater effects observed in the cross-sectional phase. The next section reports results from a similar study with inulin.

An investigation of the effects of inulin on energy, mood and cognitive function

Inulin is a natural food component found in many plants that are part of the human diet (e.g. leeks, onions, wheat, garlic, chicory and artichokes). For commercial purposes it is extracted from the chicory root by diffusion in hot water. It is added to many foods and is used to increase dietary fibre, replace fats or carbohydrates, and as a prebiotic (a stimulant of beneficial bacteria in the colon). The present study tested the hypothesis that inulin regulates the digestive system which then leads to a state of improved psychological well-being (improved energy, mood and cognitive function). It is possible that such effects may only be observed in those with irregular bowel metabolism or with reduced well-being. It is important, therefore, to collect such information at baseline prior to the start of the intervention.

Participants

In total 153 participants were recruited; however, eleven participants withdrew from the study (largely because they were unable to complete the questionnaires on a regular basis). Of those who completed the study, 51 % were female, and the age range was 19–64 years (mean age = 32 years). Fifty-six per cent were single and 58 % had received education at university. The majority of the sample was white (77·1 %) and 42 % were in full-time employment.

Design

A crossover design was used with half the volunteers having the inulin for 14 d followed by a 2-week washout and then placebo for 14 d, and the other group having the placebo and inulin conditions in reverse order. This design enabled one to determine whether effects of the inulin last after daily consumption has stopped.

Measures

Volunteers completed a battery of questionnaires at baseline, days 7, 14, 21 and 28, 35 and 42. The questionnaires assessed fatigue/energy, subjective mood, physical and mental health, bowel function and fibre intake (Smith *et al.* 2001). On a daily basis volunteers recorded their level of fatigue, mood and bowel function for that day (diary to be completed in the early evening). Measurement of cognitive performance (after Smith *et al.* 1997*b*) was assessed at the start and end of each condition, days 1, 15, 29 and 43. The tasks measured psychomotor performance (e.g. simple and choice reaction time), selective and sustained attention, episodic, semantic and working memory.

Inulin/placebo

Oligofructose-enriched inulin (also known as Synergy® 1) and placebo were provided in powder form by ORAFTI and volunteers consumed 10 g/d in two 5 g doses in tea or coffee at breakfast and in the evening. Compliance was assessed by self-report.

Statistical analysis

These involved analyses of covariance. The first factors to be entered into the model were the baseline measures that were used as covariates. These were followed by inulin/placebo, order of conditions and then the interactions of all these variables. These analyses determined whether there was a global effect of inulin, whether the effect persisted over time and whether there was a general effect on subjective well-being or whether it was more specific.

Results

Inulin intake was associated with increased wind (Q12 – see Table 1; $F(2,240) = 10·04$, $P < 0·001$). The other significant effects represented differences between both the inulin and placebo conditions from the washout period. Inulin intake was also associated with increased number of stools passed ($F(2,184) = 3·30$, $P < 0·05$; see Table 2). In contrast, inulin failed to influence any weekly measure of mood or quality of sleep (see Table 3), although it did influence weekly reports of bowel function. Inulin intake was associated with an increased discomfort from wind (Q6; $F(2,268) = 19·36$, $P < 0·001$), bloatedness ($F(2,268) = 5·54$, $P < 0·01$) and stomach pain (stomach cramps; ($F(2,268) = 3·25$, $P < 0·05$; see Table 4).

Table 1. Adjusted mean ratings of the assessed daily measures of mood and bowel function with respect to each condition and significance (*P* value; high score = greater frequency)

Measure	Inulin	Washout	Placebo	Significance
Q1 Today, how often have you felt physically fatigued?	1·43	1·40	1·43	0·73
Q2 Today, how often have you felt mentally fatigued?	1·25	1·23	1·24	0·93
Q3 Today, how often have you felt anxious?	0·96	0·98	0·94	0·71
Q4 Today, how often have you felt depressed?	0·78	0·85	0·83	0·26
Q5 Today, how often have you felt stressed?	1·17	1·17	1·14	0·77
Q6 Today, how often have you felt happy?	2·54	2·51	2·55	0·46
Q7 Today, how often have you had trouble remembering things?	0·98	0·98	0·97	0·98
Q8 Today, how often have you had problems concentrating on what you were doing?	1·09	1·08	1·10	0·91
Q9 Today, how often have you suffered from indigestion?	0·41	0·38	0·35	0·12
Q10 Today, have you suffered from diarrhoea? (1 = Yes; 2 = No)	0·06	0·05	0·05	0·48
Q11 Today, have you suffered from constipation? (1 = Yes; 2 = No)	0·06	0·05	0·06	0·93
Q12 Today, have you suffered from wind? (1 = Yes; 2 = No)	0·36	0·27	0·31	0·001***
Q13 Today, have you suffered from bloating? (1 = Yes; 2 = No)	0·18	0·14	0·16	0·06
Q14 Today, have you suffered from stomach cramps? (1 = Yes; 2 = No)	0·09	0·06	0·08	0·11
Q15 Today, how often have you had a headache?	0·61	0·73	0·60	0·004**
Q16 Today, how often have you suffered from shivering or sweating?	0·26	0·29	0·23	0·27
Q17 Today, how often have you felt energetic?	2·08	2·00	2·08	0·05*
Q18 Today, how often have you had a sore throat or swollen glands?	0·34	0·41	0·29	0·05*
Q19 Today, have you suffered from a cold or influenza? (1 = Yes; 2 = No)	0·05	0·08	0·08	0·16
Q20 Today, have you had problems sleeping? (1 = Yes; 2 = No)	0·17	0·16	0·15	0·49
Q21 Today, how often have you felt refreshed?	2·02	1·99	2·04	0·33
Q22 How much exercise have you taken today?	0·93	0·93	0·92	0·92
Q23 Have you taken any medication today? (1 = Yes; 2 = No)	0·11	0·15	0·13	0·06
Q24 How much alcohol have you had to drink today?	0·80	0·78	0·76	0·37
Q25 Today, how often have you felt hungry?	1·80	1·84	1·83	0·58
Q26 How energetic have you been today?	0·96	0·97	0·99	0·42
Q27 How have you felt your weight to be today?	1·02	1·05	1·01	0·12
Q28 Today, do you feel more energised?	0·95	0·95	0·98	0·36
Q29 Today, do you feel revitalised?	0·92	0·91	0·95	0·34
Q30 Today, do you feel you have more 'get up and go'?	0·94	0·94	0·99	0·15
Q31 Today, do you feel less lethargic?	0·95	0·95	0·95	0·90
Q32 Today, do you feel less sluggish?	0·95	0·95	0·97	0·82
Q33 Today, do you feel lighter?	0·95	0·95	0·95	0·93

* $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Table 2. Adjusted mean ratings of the daily record of bowel evacuations with respect to each condition (SEM) and significance (*P* value)

Measure	Inulin	Washout	Placebo	Significance
Motions	1·7 (0·09)	1·7 (0·09)	1·7 (0·09)	0·90
Stools passed	3·6 (0·25)	3·2 (0·2)	3·4 (0·2)	0·04*

* $P<0·05$.

Table 3. Adjusted mean ratings of the assessed weekly measures of mood and quality of sleep with respect to each condition (SEM) and significance (*P* value; high score = greater fatigue, etc.)

Measure	Inulin	Washout	Placebo	Significance
Fatigue	24·4 (2·4)	23·5 (2·3)	23·5 (2·3)	0·36
Emotional distress	32·3 (2·4)	32·6 (2·4)	31·6 (2·4)	0·52
Somatic symptoms	24·9 (2·3)	24·3 (2·3)	24·0 (2·3)	0·30
Cognitive difficulties	22·0 (2·5)	21·2 (2·5)	21·5 (2·5)	0·32
Positive mood	33·3 (1·7)	32·7 (1·7)	33·4 (1·7)	0·33
Negative mood	16·4 (1·9)	17·0 (1·9)	15·9 (1·9)	0·20
HADS – anxiety	5·4 (0·8)	5·6 (0·8)	5·0 (0·8)	0·04*
HADS – depression	3·7 (0·7)	4·0 (0·7)	3·5 (0·7)	0·10
Symptom checklist	4·7 (0·7)	4·6 (0·7)	4·4 (0·7)	0·22
Fibre intake	177·6 (12·4)	177·7 (12·4)	175·7 (12·4)	0·79
Hours of sleep	7·1 (0·2)	7·1 (0·2)	7·2 (0·2)	0·18
Quality of sleep (Q1)	2·3 (0·2)	2·3 (0·2)	2·3 (0·2)	0·96
Quality of sleep (Q2)	1·304 (0·216)	1·270 (0·216)	1·245 (0·216)	0·54
Quality of sleep (Q3)	1·667 (0·225)	1·750 (0·225)	1·634 (0·225)	0·18

* $P<0·05$.

Table 4. Adjusted mean ratings of the assessed weekly measures of bowel function with respect to each condition (SEM) and significance (*P* value; high score = more frequent symptoms)

Measure	Inulin	Washout	Placebo	Significance
Constipation	0·40 (0·15)	0·43 (0·15)	0·41 (0·15)	0·96
Diarrhoea	0·47 (0·17)	0·41 (0·17)	0·44 (0·17)	0·51
Indigestion	0·41 (0·12)	0·37 (0·12)	0·33 (0·12)	0·19
Nausea and/or vomiting	0·14 (0·08)	0·18 (0·08)	0·14 (0·08)	0·37
Stomach pains (i.e. cramps)	0·51 (0·14)	0·38 (0·14)	0·41 (0·14)	0·041*
Wind	1·55 (0·23)	1·15 (0·23)	1·26 (0·23)	0·001***
Poor appetite	0·47 (0·16)	0·48 (0·16)	0·58 (0·16)	0·11
Weight loss/feeling slimmer	0·32 (0·13)	0·37 (0·13)	0·31 (0·13)	0·55
Pain in bowels	0·30 (0·12)	0·25 (0·12)	0·29 (0·12)	0·58
Incomplete evacuation of bowels	0·58 (0·18)	0·60 (0·18)	0·57 (0·18)	0·85
Bloatedness	0·81 (0·18)	0·57 (0·18)	0·72 (0·18)	0·004**

*$P<0·05$, **$P<0·01$, ***$P<0·001$.

Mood and performance. Inulin failed to influence any measure of mood (see Table 5). There were no significant main effects or higher-order interactions. Inulin failed to influence any measure of the psychomotor tasks (see Table 6).

Inulin intake was associated with lower *place repetition effect* ($F(1,138) = 5·57$, $P<0·05$; see Table 7). This means that when taking inulin volunteers were faster at responding to targets shown in the same location as the previous trial. Given the large number of analyses conducted one should treat this with caution, as it may be a chance effect.

Inulin intake was associated with lower *S–R compatibility* ($F(1,138) = 6·80$, $P<0·01$; see Table 8). This means that when taking inulin volunteers were relatively quicker at more difficult (incompatible) responses. Given the large number of analyses conducted one should treat this with caution, as it may be a chance effect. Inulin had no effect on any aspect of memory (see Table 9).

Summary

The present study investigated whether ingestion of inulin altered digestive functioning, well-being and cognitive performance. No negative side-effects of taking the inulin were reported, which suggests that it is a safe product to use. Similarly, no negative side-effects were reported on either a daily or weekly basis apart from a slight increase in digestive problems (e.g. more wind). No negative effects were found in the performance data, which again shows that it is a safe product.

Table 5. Adjusted mean ratings of the assessed mood measures with respect to each condition and significance (*P* value; high score = more positive mood)

Measure	Inulin	Washout	Placebo	Significance
Mood pre-test				
Alertness	247·1	246·9	247·0	0·31
Hedonic tone	190·6	194·4	192·5	0·71
Anxiety	84·6	87·0	85·8	0·34
Mood post-test				
Alertness	222·2	220·2	221·2	0·59
Hedonic tone	180·8	184·8	182·8	0·61
Anxiety	85·8	86·8	86·3	0·71

Table 6. Adjusted mean ratings of the assessed psychomotor performance measures with respect to each condition and significance (*P* value)

Measure	Inulin	Washout	Placebo	Significance
Fixed RT (ms)	234	234	234	0·95
Variable RT (ms)	324	324	324	0·76
Focused attention				
Mean RT (ms)	397	399	398	0·60
Mean RT agree/disagree (ms)	406	406	406	0·30
Mean errors	7·8	8·1	7·9	0·23
Long RT	0·545	0·548	0·546	0·90
Categoric search				
Mean RT (ms)	515	509	512	0·40
Mean errors	7·1	7·5	7·3	0·66

RT, reaction time.

Table 7. Adjusted mean ratings of the assessed sustained and selective attention performance measures with respect to each condition and significance (*P* value)

Measure	Inulin	Washout	Placebo	Significance
Vigilance				
Total hits (number)	17·8	17·6	17·7	0·40
Total false alarms (number)	13·5	12·9	13·2	0·39
Mean RT (ms)	701	703	702	0·63
Eriksen effect (ms)	0·7	−0·5	0·1	0·35
Spatial uncertainty (ms)	94·8	92·4	93·6	0·48
Place repetition effect (ms)	17·4	24·0	20·6	0·02**

RT, reaction time.
**$P<0·01$.

Table 8. Adjusted mean ratings of the assessed stages of processing performance measures with respect to each condition and significance (*P* value)

Measure	Inulin	Washout	Placebo	Significance
Categoric search				
Encoding (ms)	16·7	20·4	18·5	0·39
S–R compatibility (ms)	18·6	22·2	20·4	0·01**
Focused attention				
Encoding (ms)	27·6	28·1	27·9	0·90

**$P<0·01$.

Table 9. Adjusted mean ratings of the assessed memory performance measures with respect to each condition and significance (*P* value)

Measure	Inulin	Washout	Placebo	Significance
Immediate recall (number; maximum = 20)	9·0	9·3	9·1	0·24
Delayed recall (number; maximum = 20)	6·9	6·9	6·9	0·53
Recognition memory				
Correct hits (number; maximum = 20)	14·8	14·8	14·8	0·49
Correct RT (ms)	1015	1028	1022	0·63
Correct rejections (number; maximum = 20)	16·2	15·8	16·0	0·51
Correct rejection RT (ms)	1028	1016	1022	0·50
Verbal reasoning				
Trials completed	49·8	51·9	50·8	0·95
% Correct	86·8	86·6	86·7	0·82
Semantic memory				
Trials completed	66·6	67·3	66·9	0·32
% Correct	94·7	95·1	94·9	0·59
Spatial memory				
% Correct	60·3	64·6	62·4	0·26

RT, reaction time.

The absence of beneficial effects of inulin cannot be explained in terms of a lack of statistical power or use of insensitive measures. Indeed, the association between fibre intake and mental health at baseline that had been obtained by Smith *et al.* (2001) was also found in the present dataset. It is possible, therefore, that the sample tested here already had appropriate gut flora. Indeed, the increase in wind does not reflect an increase in beneficial bacteria such as bifidobacteria (G. Gibson, unpublished results). This suggests that future studies should either screen gut flora prior to an intervention or that we need better markers that identify such individuals. Alternatively, there may be several types of effects occurring and some may counteract the others (e.g. a beneficial prebiotic effect may be counteracted by increased discomfort due to flatulence). Another problem with this type of study is the lack of control over other aspects of diet and behaviour.

Overall conclusions

The research described in this article has shown that it is possible to operationalise the concept of well-being and assess the impact of nutritional manipulations on a range of outcomes. Nutritional influences on well-being have been demonstrated using a variety of paradigms aimed at identifying both acute and longer-term effects. These effects have been found using both subjective reports and objective measurement of function. Other researchers have replicated a large number of these findings and the methodology can now be applied to new topics. A preliminary assessment of effects of inulin has been made and further research will allow us to determine whether it does increase the well-being of the consumer.

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