Italian breakfast in mind: The effect of caffeine, carbohydrate and protein on physiological state, mood and cognitive performance

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A R T I C L E I N F O

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A B S T R A C T

Due to the bidirectional influence between eating and mental activity, there is a growing interest in the neurosciences in the potential of food to influence mental states. Breakfast is the most investigated meal since it is supposed to influence satiety, mood and cognitive performance for the rest of the day. However, there is insufficient consistency among studies to draw firm conclusions about the short-term influence of carbohydrates and proteins on self-reported physiological state and mood. In order to shed light on this topic, 40 young Italian adults were involved in a single-blind randomized counterbalanced crossover experiment, in which we asked them to report on a series of visuo-analogue scales their physiological (i.e., hunger, tiredness and thirst) and affective states (i.e., happiness, excitement, activeness and relaxation) and perform 2 computer-administered cognitive tasks (simple reaction time and forward digit span) before and after having breakfast with a bitter espresso coffee and a whole wheat or a protein croissant. Our data show that breakfast improves the self-reported mood and physiological state, and also short-term verbal memory assessed by means of the forward digit span: we suppose that both croissants and caffeine played an important role in such findings. As for the reaction times, the whole wheat croissant intake determined slower reaction time compared with the protein croissant, maybe due to the higher glycemic response induced by carbohydrate ingestion. Confirming the bidirectional relationship between mind and food intake, the present findings are significant for nutrition science, since mood, physiological state and cognitive performance play a substantial role in general well-being as well as in eating behavior.

1. Introduction

There is a growing interest in the potential of food to influence psychological and physiological variables [1–3]. Glucose is the primary source of energy for the human brain [4] and an inadequate supply of glucose yields significant loss of mental function [5]. However, several factors modulate the impact of feeding on subsequent mental functioning such as the type of eating episode (i.e., breakfast, lunch, snack, dinner), the time of day, the age of the consumer, the macronutrient content of the meal, the amount of food consumed, the mode of administration and the diet history of the consumer [6,7]. Particularly, breakfast is the most investigated meal since it is considered the most important (interrupting the night-fasted state) of the day [8] and it is supposed to influence appetite, mood and cognitive performance for the rest of the day.

It is commonly believed that a regular consumption of the breakfast would be a key aspect of a healthy diet [9,10]. In addition to a positive effect of nutrients intake, observational studies indicate that regular breakfast consumers have a lower body weight [11,12] and a reduced risk of weight gain over a 10-year period [13,14] compared to individuals who do not regularly consume breakfast. However, recent randomized control trials do not support such data and do not report a beneficial effect of consuming breakfast on body weight [15,16]. The macronutrient load of breakfast may play a key role in those discordant results: in fact, many breakfast products are poorly satiating having a high glycemic index [17] whereas a protein breakfast, with a low glycemic index, has been suggested to be the most satiating meal [18–20]. Thus, the effect of breakfast on satiety depends on the influence of the specific macronutrient properties. Similarly, such macronutrients have different effects on mood and cognition since carbohydrates, proteins and fats (the main macronutrients) induce different physiological alterations that influence the neurohormonal environment and,

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consequently, affective and cognitive processes.

In general, mood is improved after eating breakfast rather than refraining from breakfast [13], an effect that may in part be associated with the breakfast-time consumption of caffeine, a known psychostimulant [21] that is often consumed as a part of breakfast in the western societies [22]. Particularly, several studies have shown that caffeine influences cognitive abilities such as alertness, reaction times, levels of attention, mental clarity, short-term memory, ability to concentrate and decision-making [23]. Furthermore, also an increase of mood and self-esteem and a slowdown in the onset of fatigue has been reported after caffeine intake [21,24]. Regarding the consumed product, several authors proposed that a breakfast rich in carbohydrates leads to a mood improvement [25–27] by increasing serotonin synthesis in the brain [28]. However, a recent meta-analysis [29] revealed no positive effects of carbohydrates on any aspect of mood.

Similar contrasting results were also found concerning cognitive performance: researchers agree that missing breakfast has deleterious effects on cognition [30,31] but a review [32] stated that differences in performance occurred depending on the macronutrient intake. Although with contrasting findings, memory seems to be the cognitive process most sensitive to macronutrient manipulations. In fact, whereas some studies reported that glucose improves memory performance [33], Fischer and coworkers [34] found that accuracy in a short-term memory task improved after protein intake. On the other hand, high-carbohydrate meals would produce sleepiness and calmness, slowing reaction times mainly within the first hour after intake [29].

Resuming, breakfast characteristics may induce metabolic and hormonal alterations capable of influencing individual's mental activity. However, there is insufficient consistency among studies to draw firm conclusions about the influence of the different macronutrients and particularly about how carbohydrates and proteins influence subjective hunger, mood and cognition. Such differences can be due to different experimental issues: for example, a number of studies have used between-subjects designs (different samples assigned to different macronutrients manipulation) or have assessed the macronutrients load after a free choice breakfast. Conversely, other studies have administered artificial drinks with different percentages of macronutrients strictly manipulated by the experimenter, which have poor external validity due to the strong difference with respect to everyday consumed products.

Thus, in order to shed light on the short-term effects of different breakfast macronutrients on subjective rating of mood and physiological conditions, we tested whether a breakfast composed of an espresso coffee coupled with a whole wheat (high-carbohydrate/low-protein) or a protein croissant (high-protein/low-carbohydrate) could influence the self-reported physiological and affective state and cognitive performance (simple reaction time and forward digit span tasks). Our sample was composed mainly of Italian young adults who often have breakfast with the aforementioned products, and, in light of the revised literature we hypothesized that:

H1. a) Having breakfast improves satiety and makes less tired, b) the protein breakfast improves satiety more than the carbohydrate breakfast;

H2. Having breakfast increases self-reported mood;

H3. a) Having breakfast improves cognitive performance, b) the protein breakfast improves reaction times more than the carbohydrate breakfast.

2. Materials and methods

2.1. Participants

Forty Italian young adults (14 males and 26 females) with a mean (*M*) age of 24.5 years, standard deviation (*SD*) ± 4.1, were recruited by means of a telephone interview. All participants were normal weight (*M* Body Mass Index = 22.6, *SD*= ± 4.5); we excluded vegetarians/vegans, people with food allergies or following a medically prescribed diet.

2.2. Procedure

We used a single-blind randomized counterbalanced crossover design, to control random variables such as the sample characteristics. We assessed the self-reported physiological and affective state as well as the cognitive performances before and after breakfast consumption, and each participant was administered with the different (blinded) croissants over two different days. This design implies a highly controlled procedure as participants are blind to the condition, thereby eliminating any expectancy effect. Actually, Green and coworkers [35] reported that the administration of a glucose drink (relative to a control drink) determined a cognitive improvement only when participants were informed about the nature of the drink.

Hence, all participants were asked to join the laboratory in the morning (9.00 AM or 10.00 AM) of two different days separated by one week (± 2 days) in a fasted state. Particularly, we asked all of them to refrain from eating, drinking (except for water) or carrying out strenuous exercise and avoid the use of medicines for the 12 h before each day session.

Each participant filled an informed consent form, including sociodemographic and biometric information. Each experimental day was divided into 3 sessions. In the 2 experimental sessions, namely the pre-breakfast and the post-breakfast sessions, participants responded to queries investigating their current affective and physiological states, then they carried out 2 computer-administered cognitive tasks (i.e., a simple reaction times task and a forward digit span). After the pre-breakfast session there was the breakfast session, in which participants had a breakfast composed of an espresso coffee (sugar-free) and a croissant (protein or whole wheat), then they rested approximately 25 min before starting the post-breakfast session in which they were re-tested with the self-reported affective and physiological questionnaires and the cognitive tasks. We decided to have a 30 min interval between the breakfast and the post-breakfast experimental session since plasma glucose levels peak some 30 min after initial ingestion [36]. Half of the participants took the whole wheat croissant on the first day and the protein croissant on the second day, and *vice-versa*.

The sessions lasted approximately 60 min (15 min for each experimental session and 30 min for the breakfast session). At the end of day 2, a debriefing was carried out in order to evaluate whether participants had realized the aim of the experiment and the differences between the croissant types.

The whole procedure (illustrated in Fig. 1) was carried out in accordance with the principles of the Declaration of Helsinki.

2.2.1. Questionnaire and cognitive tasks administered during experimental sessions

Regarding the evaluated variables, we assessed the self-reported physiological and affective states using different visual analogue scales (VAS), a rapid and widespread method to self-report perceived feelings [37]. We also tested the cognitive performance in the Simple Reaction Times (SRT) and the Forward Digit Span (F-DS) tasks: these tasks are commonly used in this investigation field, measuring two basic cognitive processes differing substantially from one another [32]. In fact, both tasks require a high level of attention, but whereas for the SRT it is fundamental the link between visual perception and motor response/readiness (i.e., alertness), the F-DS requests an accurate phonological encoding of the presented digits followed by recall abilities mediated by working memory processes (i.e., short-term verbal memory).

At the beginning of both experimental sessions, participants responded to 8 questions regarding their current affective and subjective physiological state. Such questionnaire was administered and recorded

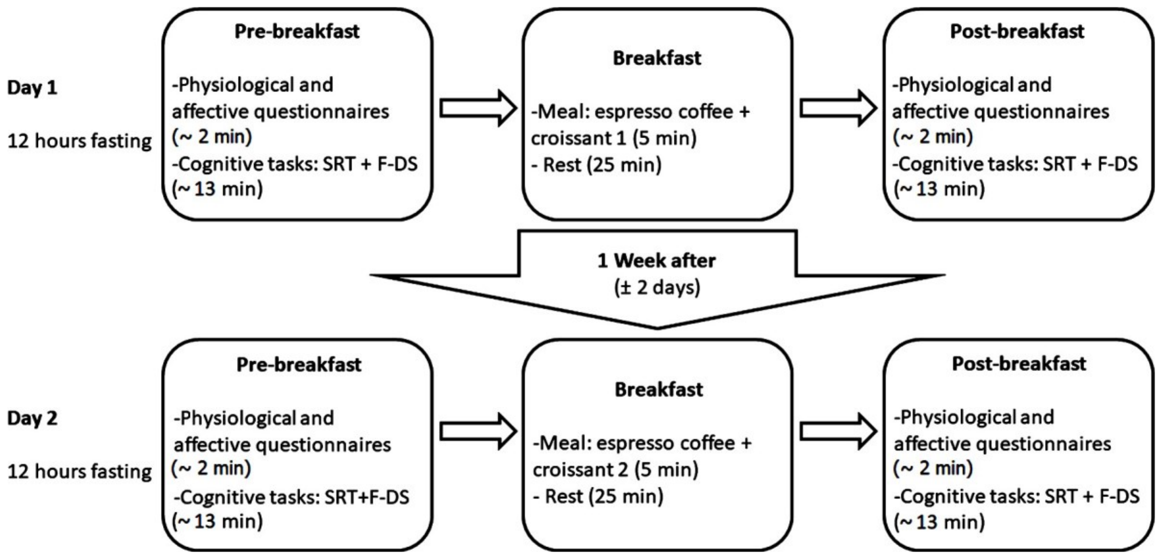

Fig. 1. Procedure used in the study. Participants were administered the same questionnaires and cognitive tasks (SRT = Simple Reaction Time task; F-DS = Forward Digit Span), before (pre-breakfast session) and after (post-breakfast session) the intake of a whole wheat or a protein croissant. Both the order of the croissant types and the cognitive tasks were counterbalanced between participants.

by Qualtrics survey software, and participants provided responses by clicking with the mouse on the appropriate point of a VAS.

The 4 questions assessing the current self-reported physiological state [38,39] were the following:

a) "How much time has passed since your last food intake?" (With the two extremes labeled: 0 "less than an hour" and 100 "more than 5 h").
b) "How hungry are you now?" (With the two extremes labeled: 0 "not at all hungry" and 100 "very hungry").
c) "How thirsty are you now?" (With the two extremes labeled: 0 "not at all thirsty" and 100 "very thirsty").
d) "How tired are you now?" (With the two extremes labeled: 0 "not at all tired" and 100 "very tired").

The question a) was used in order to ensure that all participants were in fasted state when they arrived at the laboratory.

The 4 questions assessing the self-reported affective state (Benton & Brock, 2010) were the following:

e) "How do you feel sad/happy now?" (With the two extremes labeled: 0 "sad" and 100 "happy")
f) "How do you feel bored/excited now?" (With the two extremes labeled: 0 "bored" and 100 "excited")
g) "How do you feel inactive/active now?" (With the two extremes labeled: 0 "inactive" and 100 "active")
h) "How do you feel stressed/relaxed now?" (With the two extremes labeled: 0 "stressed" and 100 "relaxed")

The order of presentation of questions was randomized. After filling the questionnaire participants carried out two computer- administered cognitive tasks:

i) the SRT task measures the basic cognitive processes of visual perception and motor response execution (alertness). In particular, we required participants to press the space bar of a laptop keyboard as quickly as possible in response to the presentation of a black cross (i.e., the target) appearing on the center of a white computer screen. There was a random (1000–3000 ms) inter-stimulus interval between trials. One-hundred target stimuli were presented, split for analysis into five trial blocks of 20 stimuli each, in order to assess changing in responsiveness during the task;
ii) the F-DS is a task used to assess short-term verbal memory. Particularly, we required participants to recall (using the keyboard for response) digit sequences of different length, named spans, composed of digits from 1 to 9 (no zero). The total number of trials was 25: after 5 trials of the same span length, disregarding the correct or incorrect recalls, the span increased by one digit in the next trial. The first span was composed of 4 digits whereas the last one of 8 digits. Each digit was pronounced by a speaker at the rate of 1 digit per second, digitally recorded (44.1 kHz, 16 bits), and normalized in mean sound intensity (70 dB SPL). After each computer-spoken digit span (displayed on a blank white screen), participants were prompt to response with the instruction "Please, press the digits in the same order that you have listened to, then press "Enter" key to confirm. You can use the backspace key to delete and rectify your response" shown on the screen (in Italian). Below such instruction the digits typed by the participants were shown in real-time. There was no response time limit and no-one feedback (correct/incorrect) was provided to the participants after the response. The inter-trial interval was of 2 s.

2.2.2. *Breakfast session*

After the pre-breakfast session, the experimenter brought in the experimental room the breakfast composed of an espresso coffee and a packaged croissant. Then the participant was left alone for breakfast (5 min ca.) and rest (25 min ca.). The croissant could be whole wheat or protein and the order of administration was counterbalanced between the two days.

This breakfast was chosen due to its widespread use in the Italian population, that typically have breakfast with an espresso coffee (bitter or with a variable content of sugar and/or milk) and a sweet snack, as croissants (without or with variable filling), cookies etc. Particularly, we decided to use a sugar-free espresso coffee to avoid adding carbohydrates to those present in the croissants. Also, we chose whole wheat and protein croissants since they are widely eaten nowadays to avoid weight gain or with the aim to lose weight, and because they are visually and nutritionally comparable, except for carbohydrate and protein content.

The espresso coffees were prepared with an espresso machine in a cafeteria near the laboratory and served in a 50 ml take away paper cup. The whole wheat croissant (high-carbohydrate/low-protein, brand

“Conad”) and the protein croissant (high-protein/low-carbohydrate, brand “Isomed”) were presented in a similar transparent plastic package. We chose these specific brands because the two croissants were comparable for weight, fat and caloric content, whereas they differed only for carbohydrates, protein amount, and fibers, this latter little considered by the literature on the short-term psychological effect since they are not hydrolyzed by the human digestive tract enzymes. All the nutritional information is reported in Table 1. Package and the croissants visual and texture features (color and consistency) were very similar, as confirmed by the participants during the debriefing.

2.3. Data analysis

We were interested in analyzing the effects of the different croissants on short-term affective state/cognitive performance. Thus, we compared the self-reported responses and the performance of participants before and after the breakfast.

Regarding the questionnaires, our variables were the mean VAS scores for each question (ranging from 0 to 100) assessed by the physiological (excluding the question regarding the last food intake) and affective questionnaires. We carried a general linear model 2 × 2 × 7 multivariate analysis of variance (MANOVA), with the Croissant type (whole wheat, protein), the Experimental session (pre-breakfast, post-breakfast) and the Question assessing the self-reported physiological and affective state as within-subjects factors.

Regarding the cognitive tasks, the variables were the mean reaction times (RTs) to the SRT task, and the percentage of correctly recalled spans in the F-DS task. Regarding the RTs we carried out a 2 × 2 × 5 ANOVA using the Croissant type (whole wheat, protein), the Experimental session (pre, post) and the Trial block (1, 2, 3, 4, 5) as within-subjects factors. Regarding the percentage of correct recalls, we carried out a 2 × 2 × 5 ANOVA using the Croissant type (whole wheat, protein), the Experimental session (pre-breakfast, post-breakfast) and the Span length (4, 5, 6, 7, 8) as within-subjects factors. The significance threshold was set at $p < .05$ and the comparisons were tested with the Duncan’s post-hoc analysis.

Two participants were excluded from the analyses since they did not take part to the second day. We underlie that during the debriefing, participants declared they did not notice significant differences in visual or flavor between the eaten croissants.

3. Results

3.1. Questionnaire

Regarding the VAS scales, the 2 × 2 × 7 MANOVA showed that the Croissant type did not play any role. In fact, we found a significant main effect of the Question ($F_{1,\,37}$= 10.145, p< .001, η^2_p= 0.215, 1-β= 0.999), a significant interaction between the Question and the Experimental session ($F_{1,\,37}$= 27.171, p< .001, η^2_p= 0.423, 1-β= 1) and no further significant effect. Particularly, our participants self-reported they were significantly less hungry (p< .001) and less tired (p= .030), but also happier (p= .049), more activated (p< .001) and more relaxed (p= .009) after eating breakfast than before eating breakfast (regardless of which type of breakfast was consumed). All the data are reported in Table 2.

Table 1
Nutrients contained in the different croissants eaten during the breakfast session.

	Whole wheat croissant (40 g)	Protein croissant (50 g)
Kcal / KJ	175 / 732	186 / 778
Fat (saturated)	10 (5) g	10 (3.6) g
Carbohydrates (sugars)	17 (6.4) g	4 (0.5) g
Proteins	3.3 g	15 g
Fibers	1.3 g	7.5 g
Salt	0.8 g	0.6 g

Table 2
Physiological and affective VAS scores self-reported before and after the breakfast.

	Pre- breakfast		Post-breakfast		
	Mean	*SEM*	*Mean*	*SEM*	*p*
Hungry	66.01	5.32	30.85	4.70	< 0.001*
Thirsty	55.57	5.74	48.66	4.84	= 0.062
Tired	50.31	5.11	42.52	4.64	= 0.030*
Sad-Happy	59.50	4.03	66.60	4.11	= 0.049*
Bored-Excited	70.77	4.45	72.69	4.38	= 0.523
Inactive-Active	49.98	4.67	68.27	3.85	< 0.001*
Stressed-Relaxed	51.73	4.40	60.93	4.85	= 0.009*

Asterisks (*) indicate significant differences (p< .05).

3.2. Cognitive tasks

Regarding the SRT task, the 2 × 2 × 5 ANOVA carried out on the mean RTs showed a significant main effect of the Croissant type ($F_{1,\,37}$= 4.416, p= .042, η^2_p= 0.106, 1-β= 0.534), and a significant interaction between the Croissant type and the Experimental session ($F_{1,\,37}$= 9.892, p= .002, η^2_p= 0.210, 1-β= 0.865, see Fig. 2a). Particularly, Duncan’s post-hoc comparisons showed that the overall effect of Croissant type was due to slower reaction times under the whole wheat versus the protein condition (p= .003). The interaction was due to the fact that participants were slower in responding after eating the whole wheat breakfast than before eating this breakfast (p< .001) while a similar effect was not observed with the high protein breakfast.

Another significant interaction was found between the Experimental session and the Trial block ($F_{4,\,148}$= 8.027, p< .001, η^2_p= 0.178, 1-β= 0.998, see Fig. 2b). The Duncan’s post-hoc comparisons showed that, regarding the pre-breakfast session, RTs were significantly faster in the early blocks, particularly for blocks 1 and 2 compared with the late ones, namely blocks 4 and 5 (for all comparisons p< .011). The RTs in block 3 were faster compared to the RTs in block 4 (p= .020). An opposite pattern of response was found for the post-breakfast session, with slower RTs in block 1 compared to all other blocks (for all comparisons p< .04). Finally, we found a significant interaction between the Croissant type, the Experimental session and the Trial block ($F_{4,\,148}$= 3.207, p= .015, η^2_p= 0.079, 1-β= 0.818, see Fig. 2c). Particularly, Duncan’s post-hoc comparisons showed that RTs in blocks 1 and 2 after the whole wheat breakfast were slower compared with the same blocks before the same breakfast (for all comparisons p< .001), whereas RTs in the block 4 were faster after the whole wheat breakfast compared with the pre-breakfast session (p= .037). On the other hand, significantly faster RTs were observed in blocks 4 and 5 after the protein breakfast compared with the same blocks before the same breakfast (for all comparisons p< .050). In general, the RTs were slower after the whole wheat breakfast compared with the protein breakfast (for all comparisons p= .028) except for block 3, on the other hand the RTs before both breakfasts were all similar except for block 4, which were slower before the whole wheat croissant compared with the protein croissant (p= .029). All significant Duncan’s post-hoc comparisons are shown in Fig. 2c. All data are reported in Table 3.

Regarding the F-DS task, the 2 × 2 × 5 ANOVA carried out on the percentage of correctly recalled spans showed that the Croissant type did not play any role. In fact, we found a significant main effect of Experimental session ($F_{1,\,37}$=10.338, p= .003, η^2_p= 0.218, 1-β= 0.879) with higher percentage of spans recalled after the breakfast (M = 72.22%) compared with the pre-breakfast session (M = 67.50%) and a significant main effect was shown by Span length ($F_{4,\,148}$= 230.12, p< .001, η^2_p= 0.861, 1-β= 1). No further significant main or interaction effects were found. Regarding the span length, Duncan’s post-hoc comparisons showed that all the comparisons between span lengths were significant (p< .024), with the higher rate of recall for the 4-digit span (M = 98.83%) and the lower rate for the 8-digit span (M = 28.56%). All the significant comparisons are reported in Fig. 3, and all the data in Table 4.

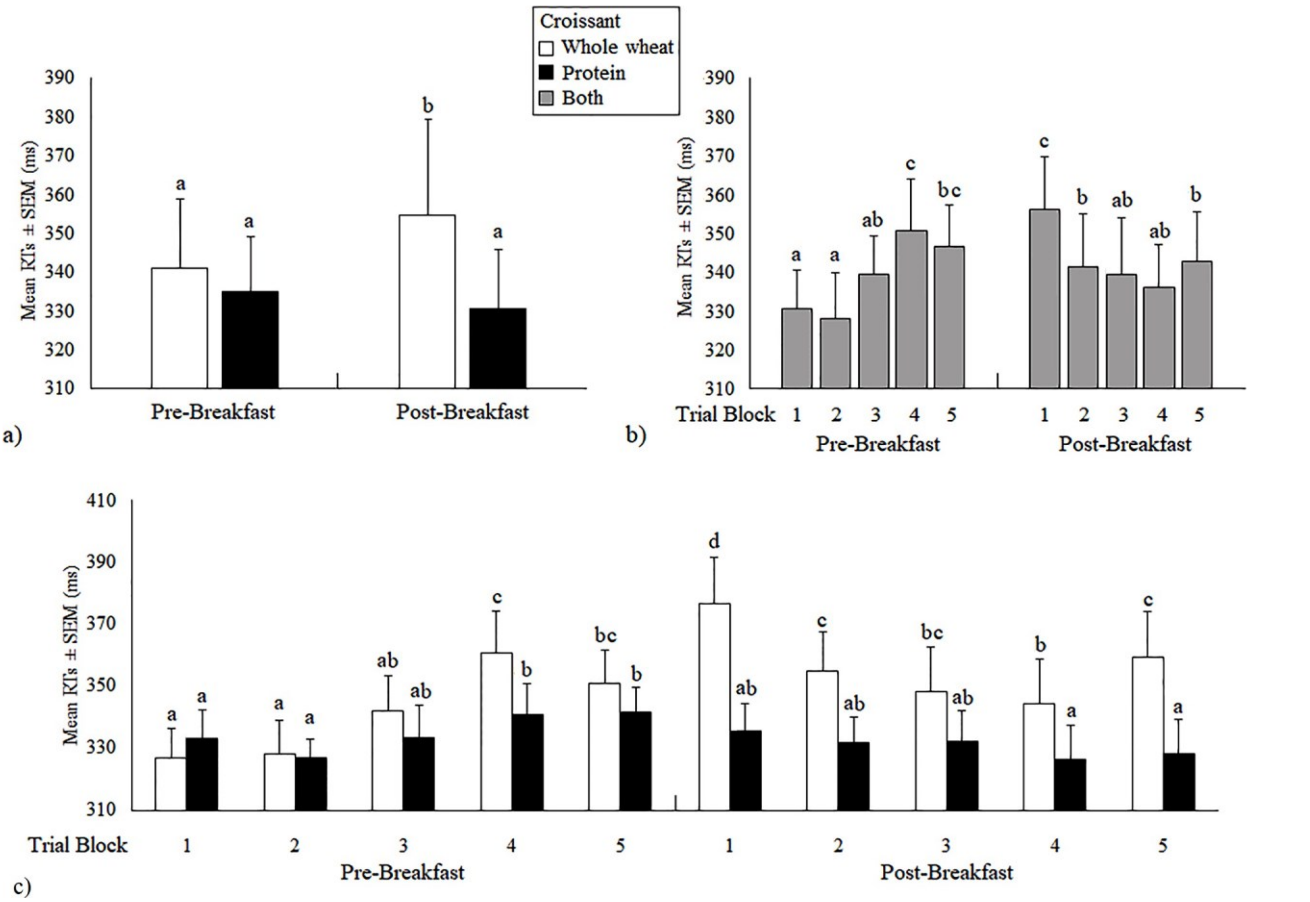

Fig. 2. Significant interactions between Croissant type x Experimental session (a), Trial block x Experimental session (b) and Croissant type x Trial block x Experimental session (c). Different letters indicate significant differences ($p < .05$). The Y axes report mean reaction times ± standard error of the means (in milliseconds).

Table 3
Mean reaction times ± standard error of the mean in milliseconds for the simple reaction time task.

Experimental session	Trial block	Croissant Whole wheat *Mean (ms)*	*SEM*	Protein *Mean (ms)*	*SEM*	Both *Mean (ms)*	*SEM*
Pre-breakfast	1	327.19	7.92	333.27	9.22	330.23	10.66
	2	327.51	8.96	325.90	5.92	326.71	8.58
	3	339.23	11.46	333.87	9.21	336.55	12.95
	4	359.45	14.25	342.67	8.38	351.06	13.68
	5	349.22	11.23	343.06	6.68	346.14	10.38
	All blocks	340.52	10.76	335.75	7.88	338.14	11.25
Post-breakfast	1	374.66	15.99	334.75	6.77	354.71	13.62
	2	353.18	12.36	330.04	7.87	341.61	12.07
	3	347.37	12.34	330.97	8.48	339.17	12.58
	4	343.78	11.46	326.29	7.68	335.04	11.83
	5	356.59	12.02	327.90	8.82	342.25	12.83
	All blocks	355.12	12.83	329.29	7.92	342.55	12.59

4. Discussions

Our data show that breakfast can improve both self-reported physiological and affective states and can affect also cognitive performance, improving short-term verbal memory and modulating reaction time with specific patterns depending on the type of croissant eaten. Particularly, our *H1a* was confirmed: having breakfast improves satiety and tiredness but, contrary to our *H1b* no difference was observed between the type of croissants. Also, our *H2* was confirmed: although breakfast improved self-reported happiness, activation and relaxation, there was no difference between carbohydrate and protein effect on such affective variables. Finally, we partially confirmed our *H3*: breakfast improved the performance in the F-DS, but not in the SRT due to a negative psychomotor effect observed after the whole wheat croissant ingestion.

First, we found that breakfast, as predicted (*H1a*), decreased subjective hunger and tiredness, irrespective of the type of consumed croissant. On the other hand, contrary to our prediction (*H1b*), the short-term (30 min) satiating effect of proteins and carbohydrates were comparable. Actually, although several studies state that protein meals are more satiating than carbohydrate ones due to the lower glycemic index [18,20], Emilien and coworkers [13] have suggested that the glycemic response has no effect on appetite, demonstrating that the

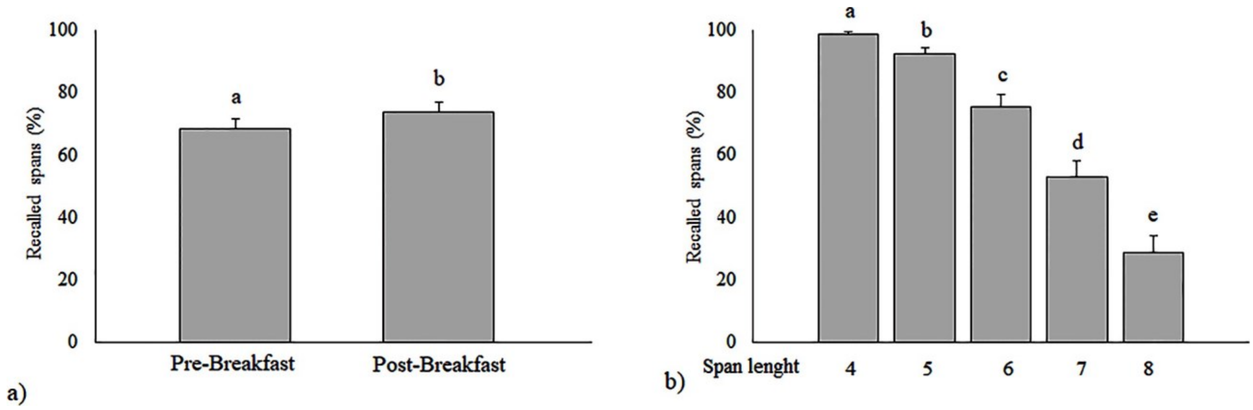

Fig. 3. Significant main effect of Experimental session (a) and Span length (b). Different letters indicate significant differences ($p < .05$). The Y axes report mean correct recalled spans ± standard error of the mean (in percentage).

Table 4
Mean correct recalled spans ± standard error of the mean for the forward digit span task.

Experimental session	Span length	Croissant Whole wheat Mean (%)	SEM	Protein Mean (%)	SEM	Both Mean (%)	SEM
Pre-breakfast	4	97.2%	1.6%	98.6%	0.7%	97.9%	1.2%
	5	88.1%	2.6%	94.7%	1.2%	91.4%	1.9%
	6	68.9%	4.3%	75.7%	2.8%	72.3%	3.6%
	7	51.4%	4.9%	50.3%	5.3%	50.8%	5.1%
	8	26.0%	4.3%	24.3%	4.1%	25.1%	4.2%
	All spans	66.3%	3.6%	68.7%	2.8%	67.5%	3.2%
Post-breakfast	4	99.8%	0.1%	99.8%	0.1%	99.8%	0.1%
	5	92.4%	1.8%	95.8%	1.1%	94.1%	1.4%
	6	79.7%	3.3%	78.8%	3.0%	79.2%	3.1%
	7	54.5%	4.8%	57.4%	4.4%	56.0%	4.6%
	8	29.9%	4.8%	34.1%	5.3%	32.0%	5.0%
	All spans	71.3%	2.9%	73.2%	2.8%	72.2%	2.9%

single macronutrients have a marginal role on perceived satiety. Also tiredness decreased similarly, independent of breakfast composition, although a recent meta-analysis revealed that carbohydrate intake was associated with higher levels of fatigue and less alertness compared within the first hour post-ingestion [29].

Regarding the subjective affective state of our sample, a general increase of mood occurred after the breakfast, again irrespective of the type of croissant eaten as predicted by *H2*. Particularly, participants reported to be happier, more relaxed and active, compared with the assessment done before the breakfast. No difference was found concerning the interest score. Similarly, Benton and Brock [7], using the same queries, found that participants who had breakfast, compared with those who had not, reported to be happier and more relaxed during the morning. Conversely, they did not find effects on the self-reported activation level. They also found a partial correlation (only for males) between the amount of carbohydrates assumed and the mood increase. Actually, several intervention studies [25–27] reported a correlation between carbohydrates assumption and mood, but a recent review of Mantantzis and coworkers [29] shed doubts on such claims demonstrating no positive effects of sugars on any aspect of mood at any time-point following their consumption. The positive effect of breakfast on tiredness and activity, differently from most studies affirming alertness decrease and fatigue increase mainly after carbohydrate ingestion [29] could have been caused by the caffeine ingestion, that is a well-known psychostimulant substance with positive effects on both sleepiness [40,41], mental energy, and arousal [42,43].

Similarly, regarding the F-DS performance, we observed that digit recall improved after the breakfast independently of the macronutrients as predicted by *H3* (see Fig. 3a). Such finding reinforces the contrasting literature about the sensitiveness of short-term memory to macronutrients intake. In the Hoyland, Lawton e Dye review [32], the authors state that none of the 4 studies measuring numeric short-term memory demonstrated significant effects of macronutrient manipulations. Other studies, focused on breakfast, showed contrasting results regarding the effect of the breakfast on short-term memory [31]. In most of these studies, caffeine was not administered but its effect was investigated by Smith and coworkers [44]: they found that coffee-free breakfast improved performance on free recall and recognition memory tasks. In contrast, the use of caffeine improved sustained attention tasks. Thus, also in this case, we can suppose that the improved performance following breakfast can be due by the interaction between the croissant macronutrients and caffeine. The digit span is a working memory task strongly influenced by attentive resources [45], fundamental for both encoding the presented digits and for keeping them in mind (phonological loop) before recalling. The importance of coffee for verbal working memory is confirmed by different research describing the improvement of such cognitive processes due to the coffee intake compared with a breakfast without caffeine, as confirmed also by neuroimaging studies [46].

Thus, we found that a breakfast composed of an espresso coffee and a croissant (both whole wheat or protein) improved mood, self-reported hunger and tiredness, and short-term verbal memory. Having breakfast is fundamental to increase mood and decrease the hunger consequent to the (fast) night, as supported by numerous research. On the other hand, the lower self-reported tiredness, the increase of self-reported activity and of the short-term memory assessed by the F-DS, are novel findings which enrich the current literature. The macronutrients of the croissant have not played any role on those outcomes, and we propose that coffee through its active principle, caffeine, can played a role for such effects.

A crucial macronutrient-related difference was found, however, for the SRT performance as predicted by *H3*: particularly, we predicted that RTs would have been faster after the breakfast but further faster after the protein breakfast compared with the carbohydrate breakfast. Such prediction was partially confirmed since, in general, breakfasts did not improve the RTs. Indeed, we observed that 30 min after the whole wheat croissant intake, the RTs to the target stimuli increased, determining a worse performance compared with that assessed in the pre-breakfast session. This effect did not occur for protein croissant (see Fig. 2a). The slower RTs after the carbohydrate breakfast were observed mainly in the first 2 trial blocks compared with the same trial blocks of the pre-breakfast session. In general, the RTs measured before the breakfast were slower in the last trials and faster in the early ones. After the breakfast, the performance reversed in direction, with faster RTs in the last trials compared with the first ones (see Fig. 2b). Our findings showed that although such dynamic is shared by both types of breakfast, the RTs measured after the protein one are at least 20 ms faster and more consistent between the different blocks compared with the RTs observed after the whole wheat breakfast (see Table 3). It seems that after the whole wheat croissant breakfast, participants had a lower alertness and concentration and needed a "warm-up" period (i.e., blocks 1 and 2) to reach RTs similar to those performed before they had breakfast. This psychomotor slowdown did not occur after the protein croissant ingestion: rather, when participants ate protein croissant, they performed faster RTs in the late blocks (i.e., 4 and 5) compared with the RTs performed to the same blocks before the breakfast. Moreover, the performance after the protein breakfast is more consistent throughout all the blocks compared with the whole wheat breakfast and the performance observed before the breakfast. Apparently, the alertness would be more sustained and stable after the protein breakfast (see Fig. 2c).

A first hypothesis on these findings concerns the glycemic response. In fact, Emilien and collaborators [13] found that plasma glucose and insulin were lower following a high-protein/low-carbohydrate breakfast compared with a low-protein/high-carbohydrate breakfast, and that the latter determined slower RTs. Similarly, Fischer and coworkers [34] found that protein-rich or balanced breakfast (carbohydrate to protein ratio = 1:1) seems to result in better overall cognitive performance, presumably because of less variation in glucose metabolism and/or higher modulation in large neutral amino acids ratios indicated by the overall glucagon to insulin ratio. Thus, we proposed that although our participants self-reported the same activation and tiredness level after both breakfasts (possibly due to the coffee effect), the higher glycemic response due to the whole wheat croissant intake determined a psychomotor slowdown, evident in the alertness outcomes provided by the SRT. Short-term verbal memory, improved following both breakfasts, would not have been impaired by the glycemic response and could instead be supported by the caffeine's effect, being the F-DS a task with a preponderant role of cognitive functions over psychomotor ones. Congruent with our findings, Michaud and coworkers [47] reported that although glucose intake improves memory, RTs could be impaired due to the drowsiness and fatigue that occur as a result of carbohydrate ingestion.

4.1. Conclusion, limitations, and further research

In summary, we demonstrated the positive effect of a typical Italian breakfast (i.e., espresso coffee and empty croissant) on self-reported physiological and affective states and on short-term verbal memory. Although we were interested on the effects of the macronutrient composition of the croissant (protein vs. carbohydrate), for sure coffee played a role in our findings. In fact, many studies showed an increase of tiredness after carbohydrates compared to protein ingestion, and coffee could have masked this effect. Similarly, the only studies reporting an improved short-term memory after the breakfast are those in which participants consumed caffeine together with foods, underlining the marginal role of macronutrient and the key role that this psychostimulant substance can have on F-DS performance. Also, we found that RTs were slower after the whole wheat breakfast compared with the protein one, demonstrating that the higher glycemic response due to the carbohydrate ingestion could cause a psychomotor impairment. Future studies could investigate the effect of a white croissant, with a higher carbohydrate load compared with the whole wheat, with the aim to deepen and confirm such suggestion. Also, further cognitive tasks (e.g., Stroop Test, Delay Discounting Task) should be considered in the future, in order to investigate the effect of macronutrients on more complex cognitive processes.

Because of the important role that espresso coffee may have had on our outcomes (and to disambiguate such effects), it would be interesting to replicate the experiment without coffee (or with a decaffeinate coffee) or using other breakfast drinks like fruit juice or milk. The use of such drinks would determine a further variance regarding macronutrients assumption, since bitter espresso coffee is only composed of water, minerals and caffein, whereas fruit juice is mainly composed of carbohydrates and milk of a variable load of carbohydrates, proteins and fats.

We point out that we assessed our variables 30 min after the meal, namely the interval in which glucose reaches its peak in the blood flow [36], so we do not know how such variables were modulated over a long-term period. Also, we did not assess objective physiological indices, such as the glycemic response, to determine the hemodynamic pattern. Further studies should consider such issues. Finally, our data were limited to a healthy Italian young-adult sample, thus future studies could recruit a more heterogenous sample. On the other hand our study has different strengths as the use of a randomized counterbalanced crossover design (i.e., each participant was tested before and after the two breakfast counterbalanced conditions), the blindness of participants to the croissant macronutrients load, and the administration of a controlled and ecological meal very familiar for our sample.

In sum, although no definitive conclusion can be drawn about the influence of breakfast on mental activity, we found that 30 min after having breakfast (espresso coffee and croissant) both short-term memory, tiredness, satiety and mood were improved, whereas simple visual psychomotor skills were impaired after whole wheat croissant, but not after protein croissant intake. Such results can be important for nutrition science, since mood, physiological state and cognitive performance play a substantial role in the general well-being of a person as well as in the eating behavior due to the bidirectional relationship between mental state and food intake.

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Disclosure statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

VM and RL conceived and designed the experiment and interpreted the data. RL and VM collected the data and VM analyzed the data and wrote the manuscript. AB and LT provided critical revisions and contributed to the final version of the manuscript by reviewing and revising the text. All authors approved the final version for submission and agreed to be accountable to for all aspects of the work.

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