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LUNCH IN CHILDREN AND ADOLESCENTS
Meal pattern and relevance for the short-term cognitive functioning

Dissertation
Submitted for the degree of Doctor oecotrophologiae (Dr. oec. troph.)
to the Faculty of Agricultural Sciences,
Nutritional Sciences and Environmental Management,
Justus-Liebig-University Giessen

by

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Saarbrücken 2015

Date of submission: 2 April 2015
Date of defence: 17 December 2015

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DANKSAGUNG

Ein herzliches Dankeschön an Herrn Prof. Dr. Clemens Kunz, der mein Interesse an einer Promotion überhaupt erst geweckt hat, für die Unterstützung während der vergangenen Jahre und die Begutachtung dieser Arbeit. Ein besonderer Dank gilt Frau Prof. Dr. Mathilde Kersting für die Idee zu diesem spannenden Promotionsthema, die Betreuung meiner Doktorarbeit am FKE, Ihr Vertrauen in meine Arbeit und ihre jahrelange Unterstützung. Insbesondere ihr Optimismus hat mich immer wieder motiviert.

Danke sagen möchte ich zudem Dr. Lars Libuda für seine fachliche Betreuung, die praktischen Ratschläge und sein offenes Ohr sowie Dr. Katharina Diethelm für die hilfreiche Unterstützung bei der HELENA-Auswertung.

Danken möchte ich auch den Lehrern und Schülern der Gesamtschule Berger Feld, Gelsenkirchen, ohne deren Studienteilnahme die einzigartigen CogniDo Daten nicht vorhanden wären. Der UNISCIENTIA Stiftung, Vaduz danke ich für die finanzielle Unterstützung der Interventionsstudie. Ein weiterer Dank geht an alle CogniDo Mitarbeiterinnen, die mich bei der Durchführung des Pretests und der eigentlichen Studie in so vielerlei Hinsicht unterstützt haben.

Bei allen Mitarbeiterinnen und Mitarbeitern des FKE bedanke ich mich für die fröhliche Arbeitsatmosphäre und überaus netten Gespräche, die lange Tage am Institut häufig kürzer gemacht haben. Danke auch für die zielführenden Diskussionen, die so manch thematische Wende in meine Doktorarbeit gebracht haben. Ganz besonderer Dank geht hierbei an meine lieben Mitdoktoradinnen, vor allem an Claudia und Gesa. Bei Gesa bedanke ich mich außerdem ganz herzlich für die konstruktiven Anmerkungen zu meiner schriftlichen Arbeit und ihr immer offenes Ohr in der Schlussphase der Arbeit.

Großer Dank gilt meinen lieben Eltern für ihre moralische und finanzielle Unterstützung sowie ihr Verständnis und ihre Geduld während meiner gesamten Ausbildung. Nicht viel weniger aufreibend als für mich waren die vergangenen Jahre für meinen lieben Simon, ohne dessen liebevolle Unterstützung die Arbeit nicht zu dem geworden wäre, was sie heute ist. Ein besonders großes Dankeschön hierfür!

WIDMUNG

Ich widme diese Arbeit meinem wunderbaren Vater, der viel zu früh von uns gegangen ist und meinen Weg zum Doktortitel nicht bis zum Ende begleiten durfte. Er wird immer ein großes Vorbild für mich sein. Denn ungeachtet seiner schweren Krankheit blieb er stets dankbar und positiv.

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ABBREVIATIONS

24HR	24-hour recall
CA	Cognitive assessment
COG	Cognitrone
5CSRTT	Five-choice serial reaction time task
CogniDo	Cognition Intervention Study Dortmund
CORSI	Corsi-Block-Tapping-Test
DGE	Deutsche Gesellschaft für Ernährung (German Nutrition Society)
DORN	Detection of repeated numbers
DST	Digit span task
EFCOSUM	European Food Consumption Survey Method
Exp.	Experiment
FKE	Forschungsinstitut für Kinderernährung (Research Institute of Child Nutrition)
HELENA-CSS	Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study
HELENA-DIAT	HELENA-Dietary Assessment Tool
OMD	Optimized Mixed Diet
PROP	Estimation of the proportions of two classes of events in a signal stream
Publ.	Publication
UK	United Kingdom
US	United States
USDA	United States Department of Agriculture
VTS	Vienna Test System
WAFA	Wahrnehmungs- und Aufmerksamkeitsfunktionen: Alertness (Perception and Attention Functions: Alertness)
YANA-C	Young Adolescent's Nutrition Assessment on Computer

SUMMARY

Lunch is a meal that is eaten at midday and differs considerably between countries regarding meal type (cold vs. hot meal) and meal size (multicourse vs. snack meal). Considering the large number of schoolchildren attending all-day schools, information on their lunch pattern and on the acute effects of lunch on their cognitive functioning are of high public health relevance. Therefore, the objectives of this thesis were to describe and evaluate potential differences in lunchtime energy and food intake of adolescents (13-17 years) at their usual lunch location (school, home or elsewhere) and to examine the impact of skipping lunch vs. having lunch on schoolchildren's (12.6 ± 0.6 years) short-term cognitive functioning.

To consider lunch pattern, the existing data of the HEalthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study (HELENA-CSS) were used, in particular lunchtime food intake data obtained from two self-administered, computerized 24-hour recalls (24HR) and data on usual lunch location. Food intake was compared to lunch of the Optimized Mixed Diet (OMD), a meal-based dietary guideline for children and adolescents. Data on the acute effects of lunch on schoolchildren's cognitive functioning were collected in a randomised crossover study. Setting was an all-day school in Gelsenkirchen, Germany. Group 1 skipped lunch on study day 1 and received lunch *ad libitum* one week later on study day 2, while group 2 was treated vice versa. On both study days tonic alertness, visuospatial memory, and selective attention were tested in the early afternoon using a computerized test battery of the Vienna Test System (VTS).

Even though the adolescents' energy intake was comparable with the OMD, their food intake was suboptimal compared to the recommendation regardless of usual lunch location. Adolescents had more potatoes and less sweets at school, and more unsweetened drinks (water, coffee and tea) and vegetables at home when each compared with the other locations. Food intake of adolescents getting their lunch elsewhere was characterised by the smallest amounts of potatoes and the highest amounts of sweets. Except for tonic alertness there were no statistically significant differences in cognitive functioning between the skipping and the having lunch day. However, the higher number of omission errors on the skipping lunch day lost significance when adjusting for multiple testing.

In conclusion, lunch on school days is improvable regardless of usual lunch location. To deduce and implement any cognition-related nutritional recommendations for schoolchildren, more research on the short-term effects of lunch on cognitive functioning is fundamental.

ZUSAMMENFASSUNG

Als Mittagessen bezeichnet man eine in den Mittagsstunden eingenommene Mahlzeit. Art (kalte vs. warme Mahlzeit) und Größe (Mehr-Gänge-Menü vs. kleinere Zwischenmahlzeit) des Mittagessens können von Land zu Land sehr unterschiedlich ausfallen. In Anbetracht der Tatsache, dass eine beträchtliche Zahl an Schulkindern bis in den Nachmittag hinein in der Schule verbleibt, sind Kenntnisse zu deren mittäglichen Mahlzeitenmustern und zum Einfluss des Mittagessens auf deren kognitive Leistungsfähigkeit am frühen Nachmittag von hoher Public-Health-Relevanz.

Ziele dieser Doktorarbeit waren deshalb, Unterschiede im Lebensmittelverzehr am Mittag bei Jugendlichen (13-17 Jahre) in Abhängigkeit vom Ort der gewöhnlichen Mahlzeiteneinnahme (Schule, zuhause, auswärts) zu beschreiben und zu bewerten und den akuten Effekt von Mittagessen vs. kein Mittagessen auf die kognitive Leistungsfähigkeit bei Schulkindern (12.6 ± 0.6 Jahre) zu untersuchen.

Für die Betrachtung der mittäglichen Mahlzeitenmuster wurden vorhandene Daten der HELENA Studie genutzt, im Besonderen Daten zum Mittagessenverzehr aus zwei 24-Stunden-Recalls und Informationen zum Ort der gewöhnlichen Mahlzeiteneinnahme. Für die Bewertung wurden die lebensmittelbezogenen Empfehlungen für das Mittagessen der am Forschungsinstitut für Kinderernährung Dortmund entwickelten Optimierten Mischkost herangezogen. Die Daten zum Einfluss des Mittagessens auf die kognitive Leistungsfähigkeit am frühen Nachmittag wurden im Rahmen einer randomisierten Crossoverstudie erhoben, die in einer Gesamtschule in Gelsenkirchen durchgeführt wurde. Gruppe 1 erhielt an Testtag 1 kein Mittagessen und eine Woche später an Testtag 2 ein Mittagessen *ad libitum*. Mit Gruppe 2 wurde andersherum verfahren. Am frühen Nachmittag erfolgte jeweils die Erfassung der tonischen Alertness, des visuell-räumliches Gedächtnisses und der selektiven Aufmerksamkeit anhand einer computergestützten Testbatterie des Wiener Testsystems.

Während die mittägliche Energiezufuhr der Jugendlichen den Empfehlungen der Optimierten Mischkost im Mittel entspricht, ist deren mittäglicher Lebensmittelverzehr unabhängig vom Ort der gewöhnlichen Mahlzeiteneinnahme nicht zufriedenstellend. In der Schule werden weniger Süßigkeiten und mehr Beilagen und zuhause mehr ungesüßte Getränke und Gemüse als jeweils an den anderen Orten verzehrt. Der Auswärtsverzehr ist durch die geringsten Mengen an Beilagen sowie die höchsten Mengen an Süßigkeiten gekennzeichnet. Außer der Nebenvariable „Auslasser“ (tonische Alertness) war kein kognitiver Parameter signifikant mit dem Verzehr einer Mittagsmahlzeit assoziiert. Dieses Ergebnis war jedoch nach Adjustierung für multiples Testen nicht mehr signifikant.

Schlussfolgernd lässt sich sagen, dass der Lebensmittelverzehr am Mittag bei Jugendlichen unabhängig vom Ort der gewöhnlichen Mahlzeiteneinnahme verbesserungswürdig ist. Um Empfehlungen zur Mittagsmahlzeit von Schulkindern unter Berücksichtigung des Einflusses auf die kognitive Leistungsfähigkeit abzuleiten und umzusetzen, ist weitere Forschung zum akuten Einfluss einer Mittagsmahlzeit auf die kognitive Leistungsfähigkeit grundlegend.

1 INTRODUCTION

1.1 Lunch

1.1.1 Definition

Colloquially, lunch is one of the main eating occasions of the day occurring at mid-day (Gatenby, 1997). There are enormous variations in the meal type and the quantity people eat for lunch, profoundly determined by culture, even in neighbouring countries (Meiselman, 2008). While lunch can be a heavier, multicourse cooked meal in Sweden or Finland, it is often a lighter sandwich meal in Denmark and Norway (Samuelson, 2000). From a scientific point of view, uniformity regarding the definition of lunch is lacking and definitions vary widely across research disciplines. According to Gatenby (1997), the majority of investigators defined a meal such as lunch on the basis of time and/ or its composition. Further criteria for the definition of a meal are social interaction, participants' self-estimation, and food variety (Oltersdorf, Schlettwein-Gsell, & Winkler, 1999). Skinner, Salvetti, Ezell, Penfield, and Costello (1985) used combined criteria considering eating occasions as lunch that (1) occur between 11.00 a.m. and 2.50 p.m. and (2) include the greatest variety of foods. Recently, the typically German hot lunch was defined as eating occasion recorded between 11.30 a.m. and 2.29 p.m. including at least one course that is usually consumed hot (e.g. soup, stew, fast food) (Alexy, Freese, Kersting, & Clausen, 2013).

1.1.2 Assessment

Diet histories, dietary records and 24-hour recalls (24HR) are suitable to assess meal-specific dietary information (Kohlmeier, 1994) all providing detailed information about preparation methods and foods eaten in combination (Thompson & Subar, 2013). Out of these dietary records and 24HR are the methods that are most frequently used in our days. For dietary records, respondents are asked to prospectively record all foods and beverages as well as their respective quantities consumed over a defined time period with a maximum of 7 days. To assess lunch-specific information by this methodology, food items can be recorded for lunches only or more likely during whole days. In the latter case, lunch needs to be defined, for example on the basis of time (retrospectively) or by self-estimation (Alexy et al., 2013; Prynne et al., 2013). Using the retrospective 24HR method, the participants are asked to remember and report the exact food and beverage intake during the preceding 24 hours or the previous day (Thompson

& Subar, 2013). The recall is typically conducted by interview which can be face-to-face or over the telephone, either computer-assisted or using a paper-and-pencil form. Furthermore, self-administered electronic application has recently become available (Arab, Tseng, Ang, & Jardack, 2011; Subar et al., 2010; Vereecken, Covents, Matthys, & Maes, 2005; Vereecken et al., 2008).

In the cross-sectional study enclosed in this thesis dietary intake data were obtained using the so-called HELENA-Dietary Assessment Tool (HELENA-DIAT), a self-administered, computerized 24HR, which was based on the Belgian-Flemish Young Adolescents' Nutrition Assessment on Computer (YANA-C) (Vereecken et al., 2005) and then culturally adapted to reach a European standard (Vereecken et al., 2008). The program leeds the respondents through a set of questions about all foods and their respective quantities eaten during the last day, meal by meal, beginning with foods usually eaten for breakfast and continuing with foods usually eaten for lunch, snacks, and evening meal.

1.1.3 Lunch habits of school-aged children and adolescents

All-day schools are well established in numerous countries around the world requiring lunch to be served at school. Despite the rising need of lunch at school, only in some countries its provision is well-organized. In the United States (US), the standardised National School Lunch Program was introduced (Ralston, Newman, Clauson, Guthrie, & Buzby, 2008), while European countries usually have their own policies to help schools providing nutritionally balanced meals, but uniformity regarding school lunch is lacking (WHO, 2006). In Germany, the number of all-day schools more than doubled from 2003 to 2007 (i.e. 6268 in 2003 vs. 12757 in 2007) and lunch provision became obligatory in those schools (Weichselbaum, Gibson-Moore, Ballam, & Buttriss, 2011). However, several studies showed that a relatively high percentage of European children and adolescents do not attend school lunch although it is provided (Dubuisson et al., 2011; Höglund, Samuelson, & Mark, 1998; Hoppu, Lehtisalo, Tapanainen, & Pietinen, 2010; Würbach, Zellner, & Kromeyer-Hauschild, 2009). A cross-sectional study in Jena conducted from 2005 to 2006 revealed that only 67% of the boys and 64% of the girls participated in the daily school lunch (Würbach et al., 2009). Similarly, a French cross-sectional food consumption survey showed that only 66% of schoolchildren aged 3–17 years had school lunch at least once weekly (Dubuisson et al., 2011). When the remaining children were asked why they did not attend school canteen, the main answer was that somebody prepares lunch at home (Dubuisson et al., 2011). But European children also bring their packed lunch from home to school (Evans, Cleghorn, Greenwood, & Cade, 2010; WHO, 2006) or do not have lunch at all (ZMP, 2005). Findings from some European studies point to an unsatisfactory nutritional quality of school lunches (Bertin, Lafay, Calamassi-Tran, Volatier, & Dubuisson, 2012; Rogers, Ness, Hebditch, Jones, & Emmett, 2007). However, school lunches seem to be better in nutritional quality than packed lunches, at least in the United Kingdom (UK) (Evans et al., 2010). On the comparison of school lunches and lunches eaten at home little information is available.

In sum, there are relatively few studies on the nutritional quality of lunch in the school context, conducted on a national or regional level, with differences in the methodology, population groups and age categories making a comparison between studies difficult.

1.1.4 Meal-based dietary recommendations for children and adolescents

Dietary recommendations commonly refer to the total diet, such as the Nutrition Circle from the German Nutrition Society (DGE) (Oberritter, Schäbethal, von Ruesten, & Boeing, 2013) and the MyPlate campaign from the United States Department of Agriculture (USDA) (USDA, 2011). Such recommendations are not necessarily suitable for school catering, since usually only certain meals - lunch and one or two snacks - are provided during school hours. Therefore, meal-based dietary recommendations need to be applied (Clausen & Kersting, 2012).

The Optimized Mixed Diet (OMD) for children and adolescents developed by the Research Institute of Child Nutrition (FKE) is - to the best of the knowledge of the author of this thesis - the only meal-based dietary concept, at least for European children and adolescents. The OMD translates scientific nutrient-based recommendations into food-based dietary recommendations for children and adolescents aged 1-18 years (Kersting, Alexy, & Clausen, 2005). The basis of the OMD is a 7-day menu taking the typical German meal pattern with 3 main meals (2 cold, 1 hot) and 2 snack meals into account. Since traditional lunch in Germany is a hot meal consisting of potatoes, vegetables, and meat or alternatively fish and not a cold meal, bread represents only minor parts of OMD lunch. Milk, milk products and fruit also play a secondary role in the lunch of the OMD as dessert after lunch is not provided. Instead, it is recommended in the OMD to have these food groups primarily during the cold meals of the day.

1.2 Cognitive functions

1.2.1 Definitions

The term ‘cognitive functions’ refers to the brain-mediated activities of receiving information from the environment, processing it internally and responding to it in the form of behaviour (Isaacs & Oates, 2008). These brain functions can be clustered into six main domains: attention, memory, executive functions, perception, psychomotor functions and language skills (Schmitt, Benton, & Kallus, 2005). Each of the cognitive domains can be further divided in more specified sub-components. Models of attention, for example, commonly include processes such as alertness/ arousal, sustained attention/ vigilance, focussed attention, selective attention, and divided attention. However to date, consensus on the precise meaning of these terms has not been reached and some terms refer to overlapping or synonymous processes, e.g. sometimes ‘focussed attention’ is used as interchangeable term for ‘selective attention’, sometimes the two terms are seen as different attentional aspects (Strauss, Sherman, & Spreen, 2006). Memory can be clustered into long-term and short-term (working) memory with the latter being further divided into the two sub-components auditory/ verbal span and visuospatial span (visuospatial memory) (Strauss et al., 2006). Psychologists also distinguish between higher-level cognitive functions and more fundamental, lower-level cognitive functions (Isaacs & Oates, 2008).

In table 1 tonic alertness, visuospatial memory, and selective attention will be further described since they are relevant for this thesis.

Table 1 Tonic alertness, visuospatial memory, and selective attention (Schellig, 2011; Wagner & Karner, 2012); on the basis of these definitions the cognitive tasks used in this thesis were developed

Tonic alertness is the physiological state of alertness, defined as the readiness to perceive and react to stimuli that occur occasionally and randomly.
Visuospatial memory is part of the working memory and assumed to be capable of temporarily storing and processing visuospatial information.
Selective attention describes the ability to deliberately direct attention towards relevant stimuli, to perceive them selectively and to implement the desired action.

The classification of separate cognitive functions does not mean that the various cognitive processes are not linked. Efficient functioning of one cognitive process (e.g. storage of information in the long-term memory) is often dependent on the integrity of other cognitive processes (e.g. attention for the relevant information, perceptual processing, and executive learning strategies) (Schmitt et al., 2005). Furthermore, cognitive functioning is known to be influenced by other factors such as physical comfort and motivation which can reciprocally influence each other (Schmitt et al., 2005).

1.2.2 Basic principles of neuropsychological testing

Neuropsychological testing is carried out for several reasons, amongst others for diagnosis, patient care and planning, treatment evaluation, and research issues (Lezak, Howieson, Bigler, & Tranel, 2012), including examination of cognitive functioning in neurologically intact samples in the latter case (Spooner & Pachana, 2006). A large variety of neuropsychological performance tasks is available by which cognitive functioning[1] can be objectively assessed (Hughes & Bryan, 2003; Lezak et al., 2012; Westenhoefer et al., 2004). The tasks are usually applied in traditional pencil-and-paper or computerized form. Using computers allows a high level of standardisation and precision. Furthermore, the scoring happens automatically and assessment time is shorter compared to pencil-and-paper tasks (Kemp, Hatch, & Williams, 2009; Woo, 2008). Nevertheless, the computerized form also has its disadvantages. Potential errors can be created in test administration and reaction time measurement due to hardware and software interactions (Cernich, Brennana, Barker, & Bleiberg, 2007). Furthermore, participants' unfamiliarity or discomfort with computers might be a problem in computerized assessment (Woo, 2008). However, this seems not to be the case for children and adolescents in our days - rather the contrary (see chapter 1.2.3).

The performance level measured by neuropsychological performance tasks is usually the quantification of speed and accuracy of responding to a task, although the focus may vary (Schmitt et al., 2005). In some memory tasks accuracy is quantified by the number of items correctly recalled and represents the most important or even the only performance indicator (Schmitt et al., 2005). This is the case for the free-recall task, in which a person is given a list of items and is asked to remember and to report the list (Franklin & Mewhort, 2002). In other tasks, in which no errors can be made, speed is mostly used as primary outcome measure (Schmitt et al., 2005). An example is the simple reaction time task in which a participant is asked to press a button as soon as a light or a sound appears (Shelton & Kumar, 2010).

Computer-based testing in this thesis has been carried out by using the Vienna Test System (VTS) (Schuhfried GmbH, Mödling, Austria). A test battery of the following three tasks has been administered: (1) Perception and Attention Functions: Alertness (WAFA), (2) Corsi-

1 In this thesis the ability to receive information from the environment, process it internally and respond to it in the form of behaviour corresponds to the terms cognitive functioning or cognitive performance.

Block-Tapping-Test (CORSI), (3) Cognitrone (COG) (Table 2). The WAFA, measuring the level of tonic alertness, is a visual simple reaction time task; primary outcome measure is speed (mean reaction time), but also accuracy (deviation of reaction time). The range of reaction times is of special interest with a great variability probably being the indication for *lapses of attention*, i.e. response omissions and extremely long reactions times (Van Zomeren & Brouwer, 1987). The CORSI, assessing the capacity of the visuospatial memory, is a task of reproducing prescribed sequences from two to eight blocks. After three sequences the number of blocks increases by one and the task closes as soon as an error in three successive sequences is made. Accuracy is quantified by the so-called immediate block span, which corresponds to the longest sequence correctly reproduced in at least two of three items. In the COG, measuring selective attention, the participants have to decide whether a displayed figure is identical with one of four figures shown or not. Whereas working time per item is unlimited, total working time is restricted to 7 minutes. Primary performance indicators are both speed (number of reactions) and accuracy (percentage of incorrect reactions). More information on the three tasks of the VTS can be found in the original article 2 (see chapter 3).

Table 2 Tasks of the Vienna Test System (VTS) used in this thesis

VTS task	Cognitive aspect	Primary outcomes	Secondary outcomes
Perception and Attention Functions: Alertness (WAFA)	Tonic alertness	- Mean reaction time - Deviation of reaction time	- Number of omission errors[a] - Number of commission errors[b]
Corsi-Block-Tapping-Test (CORSI)	Visuospatial memory	- Immediate block span[c]	- Number of correctly reproduced sequences - Number of incorrectly reproduced sequences - Number of sequencing errors[d]
Cognitrone (COG)	Selective attention	- Number of reactions - Percentage of incorrect corrections	- Number of correct reactions - Number of incorrect reactions - Mean time to react correctly - Mean time to react incorrectly

[a]stimuli to which no reaction follows within 1.5 s
[b]reactions when no stimulus had been presented
[c]longest sequence correctly reproduced in at least two of three items
[d]sequences including all the blocks of a prescribed sequence, but in the wrong order

1.2.3 Testing with children and adolescents

Assessing children's cognitive functioning is a central part of the work of psychologists in educational and health settings (Hannan, 2005). Regardless of assessment aim, testing tools need to be designed to consider the vast diversity of children's needs at different developmental stages (Stevens & DeBord, 2001). Thus, neuropsychological performance tasks should be appropriate in terms of length, format, and content depending on the sample of children who are tested. In the field of research, it is important to perform a pre-test with children of the same age group to ensure that tools are suitable (Shaw, Brady, & Davey, 2011). Children and adolescents may be more susceptible to distractors (e.g. noise or the person sitting next to them) than adults. Therefore, tests should neither be too easy nor too difficult (Hughes & Bryan, 2003) and data collection should be as short as possible (Shaw et al., 2011). A test assessment was proposed that takes no longer than one hour to complete for children aged 5 to 12 years (Hughes & Bryan, 2003). A further factor that can affect the test scores is the assessment situation. The time of day when the test is administered, the setting and whether testing is made in groups or individually can influence the testing results (Sattler, 2001). In a school setting, past experiences in this environment such as pressure to provide the 'right' answer may influence test results of children and adolescents taking part in research (Shaw et al., 2011). When testing in groups, children and adolescents can get lost, bored, fatigued or indifferent without the investigator realising these feelings and having a chance to intervene (Sattler, 2001). Getting lost can be prevented by preparing for each task by an instruction and a practice phase, which is well realisable when using computers for testing. Unfamiliarity with computers in children and adolescents is not likely since nowadays children are starting to use computers when they are still very young (Straker, Maslen, Burgess-Limerick, Johnson, & Dennerlein, 2010). Data from the Federal Statistical Office (Destatis) showed that 97% of German children aged 10-15 years used a computer the past three month before the survey (Destatis, 2013).

1.2.4 Brain development

Brain development is characterised by a rapid brain growth in the last third of gestation and early life (Benton, 2010). The largest increase occurs during the first year of life when the brain weight more than doubles from its initial weight at birth to nearly 30% of adult level (Dekaban, 1978). At the age of 2 years, the brain reaches nearly 80% of adult weight. Further peaks in brain growth were found at the ages of 7, 12, and 15 years (Epstein, 1986). Information on functional brain development is provided by positron emission tomography, an imaging technique being useful for studying brain functions and certain biochemical processes involving this organ such as glucose utilisation at different stages of cerebral maturation (Chugani, Phelps, & Mazziotta, 1987). It was found that the pattern of glucose utilisation in children is markedly different from that of adults (Chugani, 1998a, 1998b). At the age of 1 year, children's pattern of cerebral glucose utilisation is qualitatively the same as that of adults. Quantitative analysis revealed that adult rates are reached at the age of 2 years, whereas the rate at the age of 3-4 years is approximately twice as high as that of adults. These high values maintain until the age of 8-10 years, when glucose utilisation rates decline to reach adult rates at the age of 16-18 years. Correlations between glucose utilisation rates and synaptogenesis are discussed (Chugani, 1998b). Indeed, brain development occurs in multiple stages with different brain regions having its unique course of ontogeny (Figure 1) (Andersen, 2003). This seems to go along with different windows of vulnerability to environmental factors, e.g. inadequate nutrition. Interferences early in life are more likely to be of long-term relevance with widespread effects on cognitive functioning, whereas later interferences might cause functional changes which are rather subtle, temporary and reversible (Andersen, 2003).

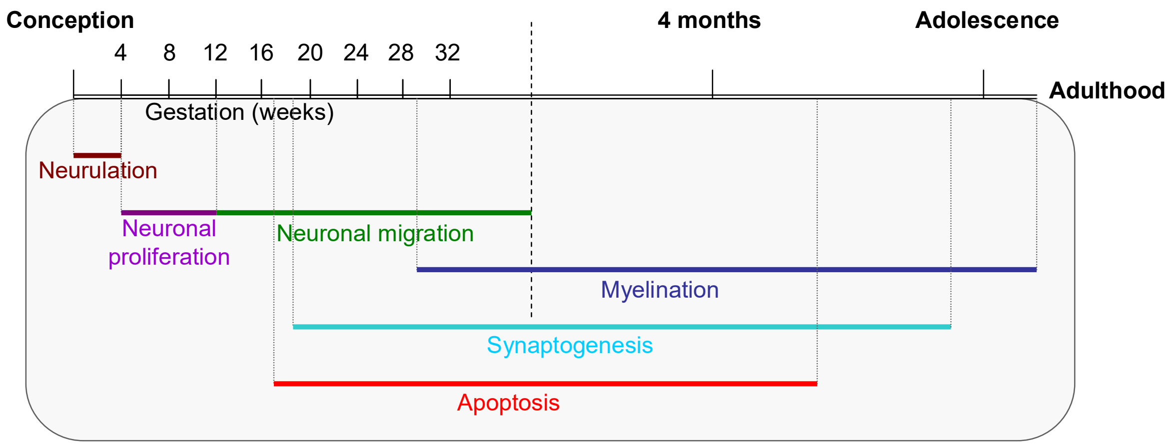

Figure 1 Major stages in brain development (modified according to Tau & Peterson, 2010)

1.2.5 Nutritional influences

Nutrition, as part of human's biological environment, has manifold effects on the brain. This can refer to brain anatomy by affecting macrostructural (e.g. frontal lobes) and microstructural development (e.g. myelination) as well as to brain physiology (Isaacs & Oates, 2008; Wachs, 2000). At least three ways in which diet affects brain physiology have been suggested (Greenwood & Craig, 1987):

(1) Food ingestion influences the availability of the precursors required for neurotransmitter synthesis (e.g. serotonin, acetylcholine)
(2) Foods provide vitamins and minerals that are essential co-factors for the enzymes synthesising neurotransmitters
(3) Dietary fats alter the composition of the nerve cell membrane.

While alterations in neuronal functioning due to (2) and (3) result from chronic dietary intake, (1) is observed after acute dietary intake (i.e. consumption of a single meal) (Greenwood & Craig, 1987).

In the context of acute dietary intake, glucose and its influence on acetylcholine synthesis should be mentioned. Glucose is one of the main sources of acetyl groups in acetyl-CoA, the precursor of acetylcholine (Tucek, 1983). Choline acetyltransferase, the enzyme required for acetylcholine synthesis, is an unsaturated enzyme. Thus, an increased supply of acetyl-CoA, resulting from increased glucose metabolism, is associated with an enhanced production of acetylcholine, which, in turn, has a role in the modulation of memory (Benton & Nabb, 2003). As glucose represents the main metabolic fuel of the brain, the rate of glucose delivery from food to the bloodstream depending on the nature of carbohydrates in the diet may influence cognitive functioning (Benton et al., 2003). Indeed, the glycaemic index as a qualitative measure of glycaemic response has been related to cognitive functioning. However, findings from intervention studies have been inconsistent according to a recent systematic review (Philippou & Constantinou, 2014). Besides the effects of glucose, the impact of other nutrients, food constituents, and supplements on cognitive functioning has been part of nutritional neuroscience (Table 3).

Table 3 Examples of nutrients, food constituents and supplements considered in the field of nutritional neuroscience (Lieberman, Kanarek, & Prasad, 2005)

Macronutrients	Micronutrients	Food constituents & supplements
Carbohydrate (glucose)	Vitamins	Caffeine
Amino acids	Iron	Tyrosine
Polyunsaturated fatty acids	Iodine	Neuroactive cyclic dipeptides
	Zinc	Phytochemicals (Polyphenolics)
	Copper	Herbal medicine (*Gingko biloba*)
	Selenium	

Not only single nutrients, food constituents and supplements may influence cognitive performance, but also complete meals. Studying meals is particularly important, since meals represent the way that people really eat (Mahoney, Taylor, & Kanarek, 2005). The interest in this area of research primarily stems from the desire to improve cognitive functioning at school and at work (Mahoney, Taylor, & Kanarek, 2005). However, some meals (breakfast) have gained more attention than others (lunch).

Earlier studies considering short-term effects of breakfast on cognitive functioning among children and adolescents provide inconsistent results. One study showed adverse effects of skipping breakfast on the accuracy of responses in problem solving, but a beneficial impact on immediate recall in short-term memory (Pollitt, Leibel, & Greenfield, 1981), whereas other trials revealed that breakfast eaters had higher scores in immediate recall, but not in other cognitive tasks (Vaisman, Voet, Akivis, & Vakil, 1996) or no effects on either memory or attention (Dickie & Bender, 1982). A systematic review considering further results from newer experimental studies suggests that having breakfast has positive cognitive effects compared to skipping breakfast in children and adolescents. However, from the studies reviewed, it is still difficult to draw firm conclusions which specific domains of cognitive functioning are most sensitive to nutritional manipulations in the morning (Hoyland, Dye, & Lawton, 2009). A plausible biological mechanism by which breakfast may affect cognitive functioning and test performance may be the metabolic changes associated with an extended overnight fast by skipping breakfast (Pollitt & Mathews, 1998).

1.3 The effect of lunch on cognitive functioning

Positive cognitive effects of breakfast do not simply mean that lunch has the same effects or shares the same underlying mechanisms. It is conceivable that the effect of lunch may be smaller than that of breakfast, since normally no longer fasting period occurs before. Considering lunch itself, there is only a small number of studies, which were recently reviewed (Müller, Libuda, Terschlüsen, & Kersting, 2013). A MEDLINE search conducted in September 2012 revealed no studies that examined the short-term effects of lunch (lunch vs. no lunch, size or composition) on children's cognitive functioning. In adults, 11 intervention studies (1981-1996) were identified with three of them comparing the effects of having lunch with skipping lunch (Table 4). Similar to conclusions drawn from the breakfast studies in children, lunch consumption had a positive effect on cognitive performance (reading task) after the lunch condition compared to the no lunch condition (Kanarek & Swinney, 1990). However, there were no effects for the other tasks such as arithmetic reasoning and sustained attention (Kanarek & Swinney, 1990). In contrast, the remaining 2 studies showed impaired cognitive functioning after having lunch compared to skipping lunch in some but not all tasks (Craig, Baer, & Diekmann, 1981; Smith & Miles, 1986a, 1986b).

It may be possible that lunch impairs some aspects of cognitive functioning, but concrete conclusions cannot be drawn for several reasons (Müller et al., 2013). First, there were only two out of three studies that indicate such an effect. Second, differences in study designs reduce comparability: different cognitive aspects were assessed as outcome (e.g. perceptual discrimination, attention or memory). Third, the methodological approach was partly inadequate: only in one study a crossover design was used; in the remaining studies, investigators chose parallel-group designs and standardisation of study conditions was partly not appropriate. Unlimited tea and coffee intake was allowed in two of the three studies.

Although only weak evidence exists for a detrimental effect of lunch on cognitive functioning, mechanisms by which lunch may have such an effect had been discussed, for example the role of post-lunch dip and changes in cortisol levels. According to Kanarek (1997), the suggestion that the so-called post-lunch dip in cognitive functioning may simply reflect an endogenous alertness rhythm was supported by observed declines in some afternoon tasks by both subjects who had eaten lunch and subjects who had skipped lunch. For other tasks, cognitive performance was more impaired in subjects who had eaten lunch when compared to those who had not, indicating that food intake may be partly responsible for the dip in the early afternoon (Kanarek, 1997). Lunch can cause increased cortisol levels in both adults and children (Follenius, Brandenberger, & Hietter, 1982; Gibson et al., 1999; Hershberger, McCammon, Garry, Mahar, & Hickner, 2004; Knoll, Müller, Ratge, Bauersfeld, & Wisser, 1984). Increased cortisol levels in adults induced by psychological stress and pharmaceuticals, in turn, has been seen to be associated with impaired cognitive performance (Bohnen, Houx, Nicolson, & Jolles, 1990; Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Lupien et al., 2005).

Table 4 Studies examining the effect of lunch vs. no lunch on cognitive functioning in adults (Müller et al., 2013)

Study	Sample	Design and lunch intervention	Cognitive assessment	Reported findings	Comments
Craig et al. (1981), UK	40 adults 63% male Median age: 23 years	Randomised controlled intervention study with 2 conditions: a) **Lunch**: standard 3-course meal b) **No lunch**: tea or coffee, walk Intervention from 12:00-13:00	Perceptual discrimination 1 h CA at 11:00 and 13:00 Subjects tested individually	Ability to discriminate impaired by condition a) when compared with pre-lunch, but not altered by condition b)	-No crossover design -Unlimited intake of tea or coffee -No information on the consumption of other foods -Groups well matched in terms of age and male-to-female-ratio
Smith & Miles (1986a, b)[a], UK	<u>Publ. 1</u> 48 adults 38% male Age not provided (university students)	Randomised controlled intervention study with 2 conditions: a) **Lunch**: standard 3-course meal b) **No lunch** Intervention from 12:00-13:15 (early) and 13:15-14:30 (late)	Sustained attention (5CSRTT) Selective attention (Stroop effect) 45 min CA at 10:45/13:15 (early) and 12:00/14:30 (late) Subjects tested in pairs	5CSRTT: response times longer after condition a) when compared with pre-lunch, but not after condition b) Stroop effect: no lunch effects	-No crossover design -No standardisation of test meal -Coffee, tea, and smoking allowed -Test meal larger than participants' habitual lunch
	<u>Publ. 2</u> see Publ.1	See Publ. 1	Sustained attention (DORN, PROP) See Publ.1	DORN: detection of fewer targets after condition a) compared to pre-lunch, but not after condition b) PROP: no lunch effects	See Publ. 1
Kanarek & Swinney (1990), US	<u>Exp. 1</u> 10 men Mean age: 21 years	Counterbalanced crossover with 4 lunch conditions: a) **Lunch**/caloric snack b) **Lunch**/non-caloric snack c) **No lunch**/caloric snack d) **No lunch**/non-caloric snack Lunch at 12:00 (early) or 12:30 (late)	Working memory (DST), Arithmetic reasoning, Reading, Sustained attention CA at 15:30 (early) or 16:00 (late) Participants tested individually	DST, Arithmetic reasoning, Reading, Sustained attention: no lunch effects	-Standardisation of breakfast -Determination of dietary habits -Irregular meal consumption as exclusion criterion -Participants asked not to eat or drink except for test meals -Small sample size

Study	Sample	Design and lunch intervention	Cognitive assessment	Reported findings	Comments
	Exp. 2 8 men College-aged	See Exp. 1 Different caloric snack (fruit-flavoured yogurt instead of confectionery product)	See Exp. 1	Reading: faster after conditions a) and b) when compared with conditions c) and d) DST, Arithmetic reasoning, Sustained attention: no lunch effects	See Exp. 1

[a]Results from a single study presented in two publications (Publ. 1, Publ. 2)
5CSRTT = five-choice serial reaction time task; CA = cognitive assessment; DORN = detection of repeated numbers; DST = digit span task; Exp. = experiment; PROP = estimation of the proportions of two classes of events in a signal stream; Publ. = publication

Irrespective of the results and the conclusion, findings from adult studies are not necessarily transferable to children, since physiological brain differences exist between children and adults such as rapid growth and higher metabolic rates in several developmental stages of childhood (see also chapter 1.2.4).

2 OBJECTIVES, RESEARCH QUESTIONS, AND APPROACHES

Considering school systems with all-day schools being established in numerous countries around the world, there is an existing debate about lunch provision. However, to date, lunch has gained less interest in nutrition research when compared to breakfast. As has been presented in the introduction, there is

(I) scarce data on adolescents' lunchtime food intake in the school context and

(II) no data on the effects of skipping vs. having lunch on schoolchildren's cognitive performance.

Thus, to address these open questions the two objectives (Objective I und Objective II) were examined in this thesis.

Objective I: To describe and evaluate potential differences in lunchtime energy and food intake of adolescents who get their lunch at school, at home or elsewhere.

Research questions
What does lunchtime energy and food intake of European adolescents at different locations look like? Is lunchtime energy and food intake at different lunch locations in line with a food-based dietary guideline (OMD)?
Research approach
Data were derived from the **HE**althy **L**ifestyle in **E**urope by **N**utrition in **A**dolescence **C**ross-**S**ectional **S**tudy (HELENA-CSS)[2]. The overall aim of HELENA was to obtain reliable and comparable data on a variety of nutritional and health-related parameters in a random cluster sample of more than 3000 European adolescents aged 12.5-17.5 years (Moreno et al., 2008). In this analysis, 891 healthy adolescents providing plausible data on total daily and lunchtime energy intake (2 x 24HR) as well as lunch location were included. Adolescents were divided into three groups of lunch location: school, home, and elsewhere. Then, lunchtime energy and food intake at the different lunch locations was described. For the evaluation, the HELENA food groups were assigned to the OMD food groups to compare adolescent's food intake to the lunch recommendations of the OMD.

2 HELENA-CSS was supported by the European Community and coordinated by Prof. Luis A. Moreno at the University of Zaragoza, Spain. Study was conducted between 2006 and 2007 in 10 European cities: Athens (Greece), Dortmund (Germany), Ghent (Belgium), Heraklion (Greece), Lille (France), Pécs (Hungary), Rome (Italy), Stockholm (Sweden), Vienna (Austria), and Zaragoza (Spain).

Objective II: To examine the impact of skipping lunch vs. having lunch on schoolchildren's short-term cognitive functioning

Research question
Does skipping lunch compared to having lunch influence selected aspects of short-term cognitive functioning of German all-day schoolchildren?
Research approach
A randomised crossover study called **Cogn**ition **I**ntervention Study **Do**rtmund (CogniDo)[3] was conducted. Setting was a secondary all-day school in Gelsenkirchen, Germany. Participants were healthy 6th grade students (n=105). At the level of school classes, they were assigned to one of two groups. Both groups consumed a standardised breakfast during the morning break. Group 1 skipped lunch on study day 1 and received an *ad libitum* lunch 1 week later on study day 2. The order for group 2 was vice versa. At the usual beginning of afternoon lessons, tonic alertness, visuospatial memory, and selective attention were assessed using a computerized test battery of the VTS.

The information on the analytical approaches, detailed presentations of the results and discussions of specific findings can be found in the original articles.

3 CogniDo was supported by a grant from the Uniscientia Foundation, Vaduz and coordinated by Prof. Dr. Mathilde Kersting at the Research Institute of Child Nutrition Dortmund (FKE). Study was conducted in a secondary all-day school in Gelsenkirchen, Germany in close cooperation with psychologists.

3 ORIGINAL ARTICLES

Original article 1

Müller, K., Libuda, L., Diethelm, K., Huybrechts, I., Moreno, L. A., Manios, Y., Mistura, L., Dallongeville, J., Kafatos, A., González-Gross, M., Cuenca-García, M., Sjöström, M., Hallström, L., Widhalm, K., Kersting, M. & HELENA Study group. (2013). Lunch at school, at home or elsewhere. Where do adolescents usually get it and what do they eat? Results of the HELENA Study. *Appetite, 71*, 332-339.

Original article 2

Müller, K., Libuda, L. Gawehn, N., Drossard, C., Bolzenius, K., Kunz, C. & Kersting, M. (2013). Effects of lunch on children's short-term cognitive functioning: a randomized crossover study. *European Journal of Clinical Nutrition, 67* (2), 185-189.

Appetite 71 (2013) 332–339

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Research report

Lunch at school, at home or elsewhere. Where do adolescents usually get it and what do they eat? Results of the HELENA Study ☆

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A R T I C L E I N F O

Article history:
Received 19 February 2013
Received in revised form 4 September 2013
Accepted 5 September 2013
Available online 17 September 2013

Keywords:
Lunch
Energy and food intake
Europe
Adolescents
Optimized Mixed Diet
HELENA Study

A B S T R A C T

Considering the lack of uniformity regarding school meals in Europe, information on adolescents' school lunch patterns is of public health importance. Thus, the aim of this analysis was to describe and evaluate lunchtime energy and food intake of European adolescents at different lunch locations. Data on nutritional and health-related parameters were derived from the HEalthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study (HELENA-CSS). A sub-sample of 891 adolescents (47% male) with plausible data on total and lunchtime energy intake (2×24 h recall) as well as usual lunch location was considered. Food intake was compared to lunch of the Optimized Mixed Diet (OMD) for children and adolescents. Although energy intake was nearly in line with the recommendations, food intake was suboptimal compared to the OMD regardless of usual lunch location. Adolescents had more potatoes and less sweets at school, and more drinks (water, coffee and tea) and vegetables at home when each compared with the other locations. Food intake of adolescents getting their lunch elsewhere was characterized by the smallest amounts of potatoes and the highest amounts of sweets. Although lunch patterns may differ among countries, schools in Europe do not seem to reveal all their potential to offer access to a healthy lunch for adolescents yet.

Introduction

School systems and school lunch provision differ between European countries, e.g., in France, Sweden and the UK all-day schools are well-established and the provision of daily school lunch is mandatory (Dixey et al., 1999; WHO, 2006) whereas in Ireland and Norway lessons are throughout the day, but schools decide individually whether to offer lunch or not (Dixey et al., 1999; WHO, 2006). In Germany, a reorganisation of the school system from mostly part-time to all-day schooling has been carried out in recent years calling for lunch to be served at school (Weich-

☆ *Acknowledgements*: Thanks to the adolescents for their participation in the HELENA Study. The HELENA Study was carried out with the financial support of the European Community Sixth RTD Framework Programme (Contract FOOD CT-2005-007034). The content of this article reflects only the authors' views and the European Community is not liable for any use that may be made of the information contained therein. The writing group takes sole responsibility for the content of this article.
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http://dx.doi.org/10.1016/j.appet.2013.09.002

selbaum, Gibson-Moore, Ballam, & Buttriss, 2011). However, the opportunity to get lunch at school does not mean that children and adolescents take it: several studies showed that a relatively high percentage of children and adolescents do not attend school lunch although it is provided (Dubuisson et al., 2011; Hoppu, Lehtisalo, Tapanainen, & Pietinen, 2010; Höglund, Samuelson, & Mark, 1998; Würbach, Zellner, & Kromeyer-Hauschild, 2009) or do not necessarily have the complete meal served at lunch in school (Aranceta Bartrina, Perez Rodrigo, Serra Majem, & Delgado Rubio, 2004; Hoppu et al., 2010; Raulio, Roos, & Prattala, 2010). As alternatives to school lunch, children and adolescents go home for lunch (Dubuisson et al., 2011), bring their lunch from home to school (Evans, Cleghorn, Greenwood, & Cade, 2010; WHO, 2006) or get their lunch elsewhere (Dubuisson et al., 2011).

Considering the lack of uniformity regarding school meals in Europe, information on adolescents' school lunch patterns are of public health relevance. This is even more relevant as lunch represents a substantial part of daily energy intake, with percentage contribution of family/school lunch to daily energy intake ranging from 16% to 39% in several European studies (Alexy, Freese, Kersting, & Clausen, 2013; Hoppu et al., 2010; Nelson, Lowes, & Hwang, 2007; Sjöberg, Hallberg, Hoglund, & Hulthen, 2003). Moreover, an inadequate nutrition during childhood and adolescence is associated with both the occurrence of obesity in youth (Niemeier, Raynor, Lloyd-Richardson, Rogers, & Wing, 2006) and the risk of developing common diseases, e.g., cardiovascular diseases (De Henauw et al., 2007), obesity (Lichtenstein et al., 1998; Moreno & Rodriguez, 2007) and cancer (Maynard, Gunnell, Emmett, Frankel, & Davey Smith, 2003) in adulthood.

Up to now, studies of adolescents' lunchtime food intake in the context of school days have been carried out in some European countries at a national or regional level (Hoppu et al., 2010; Nelson et al., 2007). However, differences in methodology, population groups and age categories make it difficult to use these data for a detailed evaluation of lunchtime dietary intake among adolescents in a European perspective. The HEalthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study (HELENA-CSS) provided for the first time the opportunity to examine food consumption of a large sample of adolescents across Europe using standardized, harmonized and validated instruments and procedures for dietary intake assessment.

Therefore, the objectives of this paper were (1) to describe lunchtime energy and food intake and (2) to evaluate potential differences in lunchtime energy and food intake of European adolescents who get their lunch at school (SL), at home (HL) or elsewhere (EL). For this evaluation, the Optimized Mixed Diet (OMD), a food and meal based total diet concept for German children and adolescents, was used (Kersting, Alexy, & Clausen, 2005).

Methods

Study design and population

The HELENA-CSS was a multi-center study conducted between 2006 and 2007 in 10 European cities: Athens (Greece), Dortmund (Germany), Ghent (Belgium), Heraklion (Greece), Lille (France), Pecs (Hungary), Rome (Italy), Stockholm (Sweden), Vienna (Austria), and Zaragoza (Spain). The overall aim of the study was to obtain reliable and comparable data on a variety of nutritional and health-related parameters in a random cluster sample of more than 3000 European adolescents (boys and girls aged 12.5–17.5 years) (Moreno, De Henauw, et al., 2008; Moreno, Gonzalez-Gross, et al., 2008).

Response rate (number of adolescents who completed the study divided by the total number of adolescents approached for the study) ranged from 53% to 79% between the study centers (Beghin et al., 2012).

The ethical committee of each center approved the study and signed informed consents were obtained from the adolescents as well as their parents (Beghin et al., 2008). A more detailed description of the study has been published elsewhere (Moreno, De Henauw, et al., 2008; Moreno, Gonzalez-Gross, et al., 2008).

From the present analysis, participants from Heraklion and Pecs were excluded as no nutrient intake information could be calculated for these cities due to logistical problems. Therefore, only eight HELENA centers were included in the present analysis. Overall, 1644 adolescents met the inclusion criteria (complete food intake data of two weekdays obtained by 24 h recall, lunch on at least one recall day, plausible data on usual lunch location obtained by the Food Choices and Preferences Questionnaire and data on anthropometry). Among those, 753 adolescents with implausible dietary recalls or lunch intake data according to the methods described below were excluded. Hence, the sample analyzed here included 891 adolescents (47% male).

Dietary intake

Dietary intake data were obtained using the so-called HELENA-DIAT, a self-administered, computerized 24 h dietary recall, which was based on Young Adolescents' Nutrition Assessment on computer (YANA-C), (Vereecken, Covents, Matthys, & Maes, 2005) validated in Flemish adolescents and then improved and culturally adapted by adding national dishes to reach a European standard (Vereecken et al., 2008). The program is organized in six meal occasions (breakfast – morning snacks – lunch – afternoon snacks – evening meal – evening snacks), with the participants selecting from more than 300 predefined food items and adding non-listed foods manually. Special techniques are used to allow a detailed description and quantification of foods, e.g., pictures of portion sizes and dishes. Amounts eaten can be reported as grams or by common household measures. After a short introduction by a trained researcher, the adolescents completed the HELENA-DIAT by themselves during school time while research staff was available in the classroom to assist the adolescents if necessary (Vereecken et al., 2008). Participants completed the HELENA-DIAT twice on non-consecutive days to achieve information close to habitual food intake (Biro, Hulshof, Ovesen, & Amorim Cruz, 2002). The Multiple Source Method (MSM), a statistical modeling technique, was used to estimate the usual dietary intake of nutrients and foods while correcting for within-person variability (Haubrock et al., 2011). To calculate energy and nutrient intake, data of the HELENA-DIAT was linked to the German Food Code and Nutrient Data Base (BLS II.3.1., 2005).

For adolescents having lunch on both recall days, lunch energy intake (kJ/lunch) and lunch intake of each food group (food group (g)/lunch) were calculated as mean value of the two 24 h dietary recalls. For adolescents having lunch on only one of the two recall days (6%), lunch energy intake and lunch intake of each food group at that day of dietary recording were considered. Total daily energy intake was used to identify potentially implausible recalls by comparing it to the basal metabolic rate (BMR) estimated by the equations of Schofield (1985). Using the well-acknowledged approaches of Goldberg et al. (1991) and Johansson, Solvoll, Bjorneboe, and Drevon (1998), 574 adolescents (43% male and 57% female) were classified as underreporters and 163 adolescents (61% male and 39% female) as overreporters. Both under- and overreporters were excluded from the analysis. Furthermore, data of 16 lunch specific outliers whose log-transformed values of lunchtime energy intake were less than mean −3 SD or greater than mean +3 SD were excluded (adaptation of the definition of Lioret et al. (2010)).

In the present evaluation of food group intakes only lunch, but not the total diet was considered, which requires meal-based recommendations. Thus, to compare adolescents' lunchtime intake of food groups with a meal-based dietary guideline the total diet concept of the OMD for children and adolescents developed by the German Research Institute of Child Nutrition (Kersting et al., 2005) was used. To the best of our knowledge, it is the only meal-based dietary concept of this type in Europe. It is based on an optimized menu for 7 days including a daily warm lunch.

Foods consumed during lunch were categorized into 45 predefined HELENA food groups. Then they were assigned to the 11 food groups of the OMD, e.g., the HELENA food group "cheese" was assigned to the OMD group "milk and milk products". If a HELENA food group could not be assigned to any OMD group, it was allocated as "others", e.g., meat substitutes and vegetarian products (Table 1). Recommended food group intakes for lunch were specified in gram per day. For this analysis we used the OMD lunch recommendations for boys and girls in the age groups 13–14 years and 15–18 years (see Appendix Table A1). Percentage of the age-and sex-specific OMD recommendations for lunchtime food intakes was calculated as follows:

$$\%\text{OMD}_i = \frac{\textit{mean intake}_i}{\textit{reference value}_i} * 100,$$

where i denotes the particular food group. As so-called target food groups 'drinks', 'potatoes', 'vegetables', 'meat and meat products', 'fish and fish products', and 'sweets' were considered.

Lunch location

Information on usual lunch location derived from the Food Choices and Preferences Questionnaire. A question was asked about the place where the adolescents usually get their lunch during the week with 6 possible answers: 'I get my lunch at the school restaurant/canteen', 'I bring my lunch from home', 'I go home for lunch', 'I go and buy my lunch from the local shop', 'I go and buy my lunch from a fast food shop or restaurant' and 'I don't eat lunch'. Adolescents who indicated that they normally do not eat lunch were excluded, as an allocation to the three groups (SL, HL or EL) was not possible. Remaining adolescents were divided into three groups: (1) school restaurant/canteen (school), (2) bring from home/go home (home), (3) local shop/fast food shop or restaurant (elsewhere). As interest was rather in the food source than the place, both packed lunch and lunch eaten at home were coded as lunch from home.

Sample characteristics

Information on breakfast skipping was also obtained from the Food Choices and Preferences Questionnaire. Body mass index (BMI) was calculated from height and weight (kg/m^2) (Nagy et al., 2008). Sex- and age-independent BMI standard deviation scores (SDS) were calculated via the LMS method of Cole, Bellizzi, Flegal, and Dietz (2000). Socioeconomic characteristics were assessed with a self-reported questionnaire (Iliescu et al., 2008). The adolescents reported their mothers' educational level (1) lower education/lower secondary education or (2) higher secondary education/higher education/university degree). The familial affluence scale (FAS), which was previously validated (Currie et al., 2008), was used as an indicator of the adolescents' material affluence. It was based on information about family car ownership, adolescent's own bedroom, and internet availability. Furthermore, smoking status (ever smoked: yes/no) was assessed.

Statistical analysis

Statistical analyses were performed using SAS software (SAS, version 9.13; SAS Institute, Cary, NC, USA). A p-value <0.05 was considered to indicate statistical significance. Sample weights were applied to adjust for exclusion of study participants due to insufficient data. The sampling weight calibrates the sample in that way, that it matches the European population with regard to sex and age-group. Differences in characteristics between adolescents who get their lunch at school, at home or elsewhere were tested using ANOVA for normally distributed variables, Kruskal–Wallis tests for non-normally distributed variables, and chi-square tests for categorical variables. Adolescents' intakes of food groups were calculated as medians and 10th and 90th percentiles. For comparison with the OMD the differences between dietary intakes and recommendations were determined. Kruskal–Wallis tests were

Table 1
Categorisation of the HELENA food groups in the food groups of the Optimized Mixed Diet (OMD)[a] and OMD lunch recommendation values[b] used for the present analysis.

HELENA food groups (n = 45)	OMD (n = 11/12)	OMD lunch recommendation (food group (g)/lunch)
Water; coffee and tea	Drinks	280–400
Starchy foods including potatoes; pulses; pasta; rice and other cereals	Potatoes, including pulses	231–350
Vegetables, excluding potatoes	Vegetables	170–220
Meat and meat products	Meat and meat products	35–50
Fish and fish products	Fish and fish products	14
Vegetable oils; margarine and lipids of mixed origin; butter and animal fats; nuts, seeds and olives	Oils and fats	12–17
Eggs	Eggs	12–17
Flour; bread and rolls; cereals	Bread and cereals	10–15
Fruit; olives and avocados	Fruit	10–15
Milk and yoghurt beverages; white milk and buttermilk; yogurt and quark; cheese, creams, other milk products	Milk and milk products	13–22
Chocolate; other sugar products; desserts and pudding milk based; desserts and puddings soy based; nuts and seeds (spreads); cakes, pies and biscuits; savoury snacks; sugar, honey, jam and syrup; confectionary non-chocolate; fruit and vegetable juices[c]; carbonated, soft and isotonic drinks; beer; wine and cider; other alcoholic beverages	Sweets	10–15
Sauces, other miscellaneous, products for special nutritional use, meat substitutes and vegetarian products, soy beverages, soups and bouillon	Others	13–22

[a] Kersting et al. (2005).
[b] Range of sex- and age-specific lunch recommendation values.
[c] Wind, Bobelijn, De Bourdeaudhuij, Klepp, and Brug (2005): Children and adolescents cannot necessarily distinguish fruit juice from soft drinks, lemonades or fruit tea. Thus, fruit juices were categorized into the sweet food group.

used to test differences in food group intake between adolescents who get their lunch at school, at home or elsewhere. An additional analysis considering adolescents' dietary intakes adjusted for study center was conducted. As the outcome variables were not normally distributed, a logistic regression was used with values for food groups being grouped into non-, low- and high-consumers. Moreover, differences between the included and excluded adolescents (sensitivity analysis) were analyzed.

Results

Of 893 European adolescents, 0.2% ($n = 2$) had no lunch on either one of the two recall days and were therefore excluded. Of the remaining 891 adolescents, 67% ($n = 596$) got their lunch at home (HL), 26% ($n = 231$) participated in school meals (SL), and 7% ($n = 64$) got their lunch elsewhere (EL).

Significant differences between SL, HL and EL were observed for all main characteristics except for sex and maternal education (Table 2). SL had the lowest BMI-SDS and the highest percentage of high familial affluence. Furthermore, they are characterized by the lowest numbers of smokers and breakfast skippers. HL had the highest BMI-SDS and the lowest percentage of high familial affluence. EL were the oldest and characterized by the highest numbers of smokers and breakfast skippers.

Absolute lunchtime energy intake of the European adolescents ranged from 2425 kJ in SL to 2927 kJ in EL (data not shown). There were no significant differences in lunchtime energy intake between the adolescents who usually get their lunch at school, at home or elsewhere. Absolute lunchtime dietary intake stratified by usual lunch location and food group is shown in Fig. 1. The highest intake levels were found for drinks, sweets, and potatoes (in descending order). Intake levels of fish and fish products, oils and fats, as well as eggs were the lowest regardless of lunch location.

The lunchtime energy and food intake of the European adolescents compared to the OMD stratified by usual lunch location is shown in Table 3. Energy intake levels of 93–109% of recommendation indicate that lunchtime intake was nearly in line with the OMD. In contrast, despite significant differences in lunchtime food intake (except for meat and meat products, eggs and fruit) between the three lunch locations intake of (target) food groups was suboptimal compared to the OMD at all lunch locations. For drinks, the HELENA boys and girls fulfilled the recommendations by only 31–57% with the highest values for those adolescents who get their lunch at home. Median vegetables and potatoes (including pulses) intakes reached only 7–17% and 16–41% of the OMD recommendations, respectively, with the highest intakes of vegetables in HL and of potatoes in SL. The OMD recommendations for fish and fish products were not reached at all. In contrast meat intake exceeded the recommendations by 16–39%. For the sweet food group (including sweetened beverages), HL and especially EL highly exceeded the recommendations (417% and 1550% of recommendation, respectively). In contrast, median sweet intake was 0% of the OMD recommendations in SL.

Table 2
Main characteristics of the HEalthy Lifestyle in Europe by Nutrition in Adolescents (HELENA) study sample ($n = 891$) by usual lunch location.

Characteristics	School ($n = 231$)			n	Home ($n = 596$)			n	Elsewhere ($n = 64$)			n	P^*
Age (years)	13	15	16	231	13	15	17	596	14	16	17	64	<0.001
Male (%)	42.7			231	48.6			596	49.4			64	0.3
BMI-SDS	0.1	1.1		231	0.4	1.1		596	0.3	1.1		64	0.004
High maternal education (%)[a]	70.4			215	67.0			571	66.5			64	0.6
High familial affluence (%)[b]	50.9			231	25.6			596	47.9			64	<0.001
Ever smoked (%)	34.9			228	38.2			593	61.9			63	<0.001
Often breakfast skipping (%)[c]	5.7			231	17.3			594	31.0			64	<0.001

Note: Data expressed as weighted frequencies, means (SD) or medians (10th and 90th percentiles).
* $p<.05$.
[a] Higher secondary education and higher education or university degree.
[b] Based on information about family car ownership, adolescent's own bedroom, internet availability, and computer ownership.
[c] Strongly agree with this statement from the Food Choices and Preferences Questionnaire.

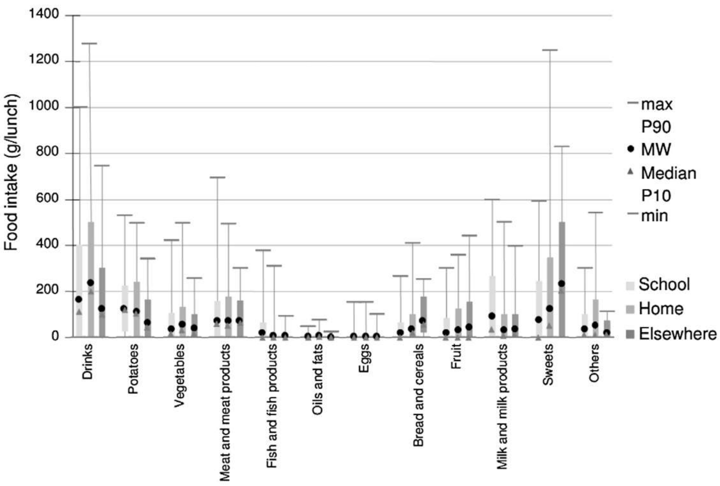

Fig. 1. Food intake (g/lunch/adolescent) of the HEalthy Lifestyle in Europe by Nutrition in Adolescents (HELENA) study sample ($n = 891$) by usual lunch location and food groups.

Table 3
Dietary intake of food groups compared to the Optimized Mixed Diet (OMD) of the Healthy Lifestyle in Europe by Nutrition in Adolescents (HELENA) study sample (n = 891) by usual lunch location.

Energy and food groups	% Lunch of the OMD									P^a
	School (n = 231)			Home (n = 596)			Elsewhere (n = 64)			
	10th	50th	90th	10th	50th	90th	10th	50th	90th	
Energy	50.3	93.1	152.1	56.7	99.5	170.5	49.1	108.5	159.9	0.06
Drinks	0	31.4	125	0	57.1	150	0	28.6	85.7	<0.001
Potatoes, including pulses	8.7	40.7	78.9	0	35.2	86.6	0	15.8	56.8	<0.001
Vegetables	0	8.8	52.6	0	16.7	69.7	0	7.3	49.9	0.002[b]
Meat and meat products	0	130	387.5	0	115.6	408.7	0	138.6	393.8	0.4
Fish and fish products	0	0	446.4	0	0	89.3	0	0	178.6	<0.001
Oils and fats	0	0	100	0	16.5	158	0	0	38.8	<0.001[b]
Eggs	0	0	116.7	0	0	94.2	0	0	93.8	0.4
Bread and cereals	0	0	500	0	160	751.9	0	384.6	1178.9	<0.001
Fruit	0	0	700	0	0	903.8	0	0	1153.9	0.05
Milk and milk products	0	182.3	1562.5	0	39.8	522.7	0	68.4	596.6	<0.001[b]
Sweets	0	0	2000	0	416.7	2650	0	1550	3340	<0.001
Others	0	73.4	615.4	0	76.9	1000	0	44.8	363.6	0.2

Note: Data expressed as medians (10th and 90th percentiles).
[a] $p<.05$.
[b] Lost significance when adjusting for study center.

The bread and cereals food group was not a component of school meals (0% of recommendation), but HL and EL exceeded the recommendations by 160% and 385, respectively. The median milk and milk product intake was about 182% for SL, but was below the recommendations in HL and EL (40% and 68% of recommendation, respectively). The OMD recommendation for eggs, fruit as well as oils and fats were not reached, except marginally for the intakes of oils and fats in adolescents who get their lunch at home (17% of recommendation).

Adjustment for study centers showed similar results, except for the food groups vegetables, oils and fats as well as milk and milk products which were significant before and lost significance after adjustment. The sensitivity analysis revealed that the included adolescents differed significantly from the excluded adolescents for most food groups (except for drinks, meat, fish, eggs and others), with the latter having less potatoes, vegetables, oils and fats, bread and cereals, fruit and milk as well as more sweets than the former (data not shown).

Discussion

The present analysis provides for the first time evidence, based upon a comprehensive and standardized dietary assessment method, that lunchtime food intake of European adolescents is suboptimal compared to a European food based total diet concept regardless of usual lunch location. In particular, adolescents drink less than half of the recommended amount, and eat less than one third of the recommended amounts of vegetables and potatoes, but consume much more meat (products) and sweets than recommended. Although lunchtime food intake of European adolescents is not optimal, lunchtime energy intake is nearly in line with the recommendations. Regarding lunch locations, most adolescents usually get their lunch at home, a smaller proportion of adolescents participate in school meals, and only a few adolescents get their lunch elsewhere. There seem to be some advantages of both lunches from school and lunches from home when each compared with the other locations. SL had lower intake levels of sweets and higher intake levels of potatoes, while the group of HL had more drinks (water, coffee and tea) and vegetables. Data suggest that participants getting their lunch elsewhere have the unhealthiest lunch patterns characterized by the smallest amounts of potatoes and the highest amounts of sweets.

Regarding energy intake, Lachat et al. (2012) concluded in their recent systematic review that eating away from home (including school and restaurant) is an important risk factor for a higher energy intake in children and adults worldwide. In line with this, Mancino, Todd, Guthrie, and Lin (2010) observed that both food from school and food away from home were associated with a higher caloric consumption when compared to food from home in school-aged US children, especially in the older age group (13–18 years). This is not in line with our European results as no significant differences in energy intake levels between the three groups were found. However, differences in methodology make it difficult to use these data for a comparison. For example, lunch from school was defined as lunch in the school canteen in our analysis, but in the US study all foods available for purchase at school were coded as food from school, not only those offered as part of school meals (Mancino et al., 2010). Their results would probably be different when only adolescents who participated in the USDA school lunch program would be considered.

Unsatisfactory nutritional quality of school lunch was found in some European studies (Bertin, Lafay, Calamassi-Tran, Volatier, & Dubuisson, 2012; Rogers, Ness, Hebditch, Jones, & Emmett, 2007). For example, according to national recommendations, improvements of school lunch are needed in French secondary state schools for some foods/food groups (e.g., fish, high-sugar desserts) (Bertin et al., 2012). In HELENA, OMD recommendations were also not fulfilled for drinks, vegetables and potatoes. In the HELENA Study sample, the low intake level for sweets at school gets a generally positive assessment. Considering that 86% of the sweet food group in HELENA consists of fruit juices and carbonated/soft/isotonic drinks, one can assume that those beverages are fortunately not offered as part of European school lunches. Although school lunch in Europe partly needs improvement there is evidence from Finland that having school lunch is associated with a better choice of food when compared to skipping it (more vegetables, fruits, rye bread as well as milk and milk products vs more fast food and sweets) (Raulio et al., 2010).

Nutritional quality of school lunches was compared to that of lunches brought from home (packed lunches) particularly in British children and adolescents (Harrison et al., 2011; Pearce, Harper, Haroun, Wood, & Nelson, 2011; Prynne et al., 2011; Rees, Richards, & Gregory, 2008; Rogers et al., 2007). In their meta-analysis Evans et al. (2010) showed that packed lunches are worse in nutritional quality when compared to school lunches in the UK, with packed lunches providing lower amounts of vegetables and more confectionery and soft drinks (Pearce et al., 2011; Prynne et al., 2011). Regarding some food groups (sweets, including juices, confectionery and soft drinks), British study results of the comparison between packed lunches and school lunches correspond to those of HELENA. An often mentioned important difference between packed lunches and school lunches is the sugar content and the consumption of soft drinks, respectively, with children eating a packed lunch usually having sweetened drinks and children eating school lunch usually having water (Evans et al., 2010). However, in our analysis packed lunch was classified as lunch from home (as was lunch directly eaten at home), with a relatively small proportion of adolescents (15%) bringing their lunch from home. So, when interpreting the data, it should be kept in mind, that the greater part of HL went home for lunch.

To our knowledge there is little information on the comparison of school lunches and lunches eaten at home. A Spanish study showed that fish, eggs, dairy products, vegetables and cereals were more frequently eaten by SL than by children having lunch at home (López-Frías et al., 2005). In line with these results, dairy products were higher in SL when compared with HL in HELENA. In contrast, regarding fish and eggs, there were no differences between SL and HL. Vegetables were even lower in SL when compared to HL. Studies considering lunch sources often compared lunch eaten at home to lunch eaten outside the home (including restaurants, fast food shops and school canteens) (Burke et al., 2007; Vandevijvere, Lachat, Kolsteren, & Van Oyen, 2009). Given that several groups were merged together for lunch eaten outside the home, the use of these data for a comparison is difficult. However, nearly 40% of EL gets their lunch from a fast food restaurant in the HELENA Study sample. US children who ate fast food consumed more total energy and had a poorer diet quality (e.g., more sweetened beverages, fewer vegetables) compared to those who did not (Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004; Paeratakul, Ferdinand, Champagne, Ryan, & Bray, 2003).

Several limitations of this analysis need to be mentioned. Firstly, the HELENA-CSS cohort is not a fully representative European sample as it is restricted to 10 cities, but as a random selection of schools and classes within the cities was made, representativeness can be at least achieved on the city level. This procedure is anticipated to give a fair approximation of the average picture of the situation, if the objective is to describe the adolescents' characteristics (Moreno, De Henauw, et al., 2008), as was the case in our analysis. Secondly, self-reported dietary intake seems to be problematic in children and adolescents (Brady, Lindquist, Herd, & Goran, 2000) and the 24 h recall used in HELENA was identified to have substantial underreporting bias (Vereecken, Dohogne, Covents, & Maes, 2010), e.g., the consumption of drinks may be spontaneously underreported. However, due to the exclusion of over- and underreporters from our sample, systematic bias should have been reduced. We additionally excluded adolescents with 24 h recall data on dietary intake on Sunday collected on Monday and boys and girls without plausible data on usual lunch location, further reducing the sample size. However, with nearly 900 adolescents the sample size is still relatively large. A sensitivity analysis revealed that the excluded adolescents differed significantly from those included regarding all their anthropometric but only few socioeconomic (high familial affluence) and health-related characteristics (breakfast skipping, lunch on one of the recall days) respectively (data not shown) suggesting to have similar socioeconomic status and health consciousness. However, it cannot be ruled out that adolescents with extreme dietary behavior were not being considered, as the included adolescents were characterized by a better anthropometric profile. Indeed, a further analysis on differences in food group consumption compared to the OMD between the included and excluded adolescents showed that the groups differed significantly for most food groups (except for drinks, meat, fish, eggs and others; data not shown).

Thirdly, given that the dietary data was assessed using only two 24 h recalls, within-individual variability should be considered. Therefore, food intakes were corrected for within-person variations by applying the MSM method. However, a misestimating of certain food groups may be possible due to non-consumption days of rarely eaten food items (e.g., fish) and problems with the calculation of certain food items (e.g., oils and fats).

Fourthly, there are huge variations of what and how much people have for lunch. Lunch can be a heavier, multicourse cooked meal or a lighter sandwich meal. These variations are even profound for neighboring countries (Meiselman, 2008). Furthermore, national school food standards or nutritional recommendations in different European countries are not necessarily consistent with the OMD recommendations considering typical German meal pattern. In the OMD, the main components of the cooked lunch are potatoes, vegetables and meat or alternatively fish. In contrast, bread and cereals as well as milk and milk products represent only minor parts of lunch. Regarding, for example, the bread and cereals food group, in some European countries, (e.g., Finland) bread becomes integral part of a healthy school lunch (Raulio et al., 2010). With a relatively low reference value of 10–15 g (e.g., bread with soup) in the OMD the reference value can easily be exceeded supposing that adolescents from others countries than Germany (e.g., Finland) eat at lunch as they were recommended in their own country. That must be kept in mind when interpreting the data. Although the OMD was designed for German dietary habits, it is very useful to evaluate food intake in the HELENA adolescents, especially as it was adapted for adolescents' energy requirements.

It should be kept in mind when interpreting the data, that unequal group sizes (231 SL vs 596 HL vs 64 EL) as it was the case in our study sample may minimize the precision of the estimated effect. Last but not least, information on the provision of school lunch in the HELENA schools was not available.

Major strengths of the present study, besides the large sample size, are the geographical distribution of HELENA Study centers as well as the standardized and harmonized methodology. Moreover, to our knowledge, this is the first study examining the lunchtime food intake whilst taking into account usual lunch location among well-characterized adolescents across Europe.

In conclusion, the present analysis provides new evidence about lunchtime energy and food consumption of European adolescents who get their lunch at school, at home or elsewhere. Although the adolescents' lunchtime energy intake is nearly in line with the recommendations, their lunchtime food intake is unsatisfactory in the light of a food based dietary concept from a European country regardless of lunch location. Hence, a central message might be that adolescents ought not to eat more or less for lunch, but to rearrange their lunchtime food patterns. Furthermore, data suggests that participants getting their lunch elsewhere have the unhealthiest lunch patterns. The overall improvement of adolescent's lunchtime food intake might occur successively; as a first step adolescents need to be encouraged to stay in school for lunch instead of eating elsewhere. However, schools do not seem to reveal all their potential to offer a healthy lunch for everyone yet.

Appendix A

See Table A1.

Appendix B

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Table A1
Daily intake of major and minor food groups (g/day) in the lunch of the Optimized Mixed Diet (OMD) for male and female adolescents aged 13–14 and 15–18 years (Kersting et al., 2005).

Age (years)	13–14	13–14	15–18	15–18
Sex	Female	Male	Female	Male
Food groups (g/day)				
Major food groups				
Drinks	280	350	350	400
Potatoes/pasta/rice	220	280	270	330
Pulses	11	15	15	20
Vegetables	170	200	190	220
Meat and meat products	35	45	40	50
Fish and fish products	100/week	100/week	100/week	100/week
Minor food groups				
Oils and fats[a]	12	15	14	17
Eggs	12	15	14	17
Bread and cereals[b]	10	14	13	15
Fruit[c]	10	14	13	15
Milk and milk products[c]	13	20	16	22
Sweets[d]	10	13	12	15
Others	13	20	16	22

[a] e.g., for frying.
[b] e.g., for soup.
[c] e.g., in a casserole.
[d] e.g., in sweet main dishes.

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European Journal of Clinical Nutrition (2013) 67, 185–189

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ORIGINAL ARTICLE

Effects of lunch on children's short-term cognitive functioning: a randomized crossover study

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BACKGROUND/OBJECTIVES: Considering the large number of children worldwide attending all-day schools, information on the effects of lunch on short-term cognitive performance is of public health relevance. However, only adult studies investigated this issue yet. Therefore, this study examined the impact of skipping lunch vs having lunch on children's cognitive functioning in the early afternoon.

SUBJECTS/METHODS: Participants in this randomized crossover study with two groups were healthy 6th grade students of an all-day school in Gelsenkirchen, Germany. Group 1 skipped lunch on study day 1 and received an *ad libitum* lunch 1 week later on study day 2. The order for group 2 was vice versa. In the afternoon tonic alertness, visuospatial memory and selective attention were determined using a computerized test battery of the Vienna Test System. For continuous and discrete interval-scaled variables, treatment effect was estimated using the two sample *t*-test or the Wilcoxon rank-sum test, for discrete ordinal-scaled variables using generalized linear models.

RESULTS: Data on 105 children (48% male; 12.6 ± 0.6 years) were analyzed. Except for tonic alertness there were no significant differences in cognitive functioning between the skipping lunch day and the having lunch day. The higher number of omission errors on the skipping lunch day lost significance when adjusting for multiple testing.

CONCLUSIONS: In the first study on this topic lunch did not have relevant effects on children's cognitive functioning in the early afternoon. Future research needs to be done to figure out potential methodical and physiological explanations.

European Journal of Clinical Nutrition (2013) 67, 185–189; doi:10.1038/ejcn.2012.209

Keywords: child; attention; memory; diet; food services; schools

INTRODUCTION

The long-standing National School Lunch Program of the US[1] and its nutrition standards[2] set an example for a well-organized provision of school meals with the objective of health promotion in school children. In Europe, provision of school meals differs between countries: in some countries (for example, Finland, France and the UK) schools have to provide lunch everyday, whereas in other countries (for example, Austria, Ireland and Norway) schools decide individually whether to offer lunch or not.[3] In Germany, from 2003 onwards a reorganization of the school system from part-time to all-day took place,[4] requiring the provision of school meals. However, a nationwide survey in 2004 revealed that only 74% of German children attending all-day schools ate a proper lunch on most of the days; the rest of the children had it several times a week or not at all. Overall, the number of school children having a proper lunch declined further with age.[5] In line with these results, a regional study in Jena in 2005/2006 showed that only 67% of the boys and 64% of the girls participated in daily school lunch and the proportion decreased with age.[6]

One argument often used for the provision of school meals is the enhancement of children's cognitive functioning. Existing experimental studies in this area of research primarily concentrated on the impact of breakfast on children's short-term cognitive performance. Although results of earlier studies were contradictory,[7–9] a recent systematic review suggested that there were positive cognitive effects associated with having breakfast as compared with skipping it.[10] However, just because having breakfast may have positive cognitive effects in children does not mean that having lunch works in the same way, for example, the effect of lunch may be smaller than that of breakfast, as a preceding fasting period (overnight fast) does not occur.[11] Furthermore, the meal effect on cognitive functioning may be different depending on whether a nightly rest or a working phase was carried out previously. Daily variations in performance may also modify the way a meal effects cognitive functioning.

To our knowledge, no research has been performed yet concerning lunch and children's short-term cognitive performance. There is only some information from adult studies that points to an impairment of some aspects of cognitive performance after having lunch,[12–14] but these findings are not unrestrictedly transferable to children. It might be hypothesized that lunch skipping might worsen cognitive functioning in children when compared with adults owing to the relatively higher demand for energy and nutrients necessary for healthy brain function during childhood. Considering the large number of children worldwide spending their time at school until the afternoon, the lack of uniformity regarding school meals in Europe and the low school lunch participating rates in Germany, information on the impact of lunch on cognitive performance is of

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Received 18 September 2012; revised 3 December 2012; accepted 5 December 2012

public health relevance. Therefore, objective of the Cognition Intervention Study Dortmund (CogniDO) was to examine the effects of skipping lunch vs having lunch on selected aspects of short-term cognitive functioning of German all-day school children. Selected aspects of cognitive functioning were attention (tonic alertness, selective attention) and working memory (visuospatial memory), with both considered as fundamental processes having a role in other cognitive functions and everyday activities.[15,16]

MATERIALS AND METHODS

Setting and participants

Setting was a secondary all-day school in Gelsenkirchen, Germany. The school was eligible for participation, as it is attended by a large number of children ensuring a sufficient sample size and is equipped with both adequate computers for cognitive assessment and a school kitchen which provides a well-established warm school lunch. We obtained written parental consent for 121 (75%) of 161 6th grade students. In order to ensure homogeneity of the study population, five children with diagnosed learning disabilities were excluded, with information on the presence coming from the teachers. The study was approved by the Ethics Committee of the University of Bonn, Germany.

Study design and intervention

A randomized, open-label crossover study was performed with two test days (skipping lunch day, having lunch day) embedded in everyday school life (Figure 1). Study conduct was realized on the level of school classes with the first class being tested at the end of May and the last class at the beginning of July 2011 (Table 1). Within their school classes, participants were randomly assigned to one of two groups (simple randomization with replacement). One group skipped lunch on study day 1 and received lunch *ad libitum* 1 week later on study day 2 (SL–HL). The order for the second group was vice versa (HL–SL).

On both test days, subjects consumed a standardized morning snack *ad libitum* during the common morning break. The snack consisted of wholemeal bread with margarine, poultry salami or Gouda cheese and carrot sticks, water was available at any time. On the skipping lunch day, water was offered at usual lunch time at the school refectory, lunch was eaten immediately after cognitive assessment. On the having lunch day, pasta Bolognese was prepared by the school kitchen staff as usual and offered together with an apple and water at usual lunch time at the school refectory. The amount of pasta eaten was assessed by weighing the individual plates before and after having lunch by the study staff.

All participants were asked to refrain from eating and drinking (water allowed) between the morning snack and lunch as well as between lunch and cognitive assessment. In order to check whether the subjects act as they were told, we used a short questionnaire for the children to fill out at the end of the test day in which they were asked for information regarding their food consumption in the periods between the offered meals. Study materials and study conduct were pilot-tested in fifth grade students of the same school in February 2011 and relevant experiences were taken into account when carrying out the actual study (for example, reminder calls to the teachers on the day before test days).

Cognitive assessment

For cognitive assessment we used a computerized test battery of the Vienna Test System (VTS) (Schuhfried GmbH, Mödling, Austria). At the usual beginning of afternoon lessons cognitive assessment was performed; with five to 28 children per class tested at the same time. After a short verbal introduction by the study personnel, children were standardized prepared for each task by both an animated instruction phase and an error-sensitive practice phase (Figure 2).

The following three subtests were always applied in the same order:

- Perception and Attention Functions: Alertness (WAFA)—measures the level of alertness in response to a simple visual stimulus without a preceding warning signal. The test duration is 4 min. Main outcomes are the mean reaction time and the deviation of reaction time; subsidiary outcomes are the numbers of omission (stimuli to which no reaction follows within 1.5 s) and commission errors (reactions when no stimulus had been presented).
- CORSI Block-Tapping-Test (CORSI)—assesses the so-called immediate block span, which reflects the capacity of the visuospatial subsystem within the working memory. The test is a task of reproducing prescribed sequences from two to eight blocks. After three sequences the number of blocks increases by one. The test closes as soon as an error in three successive sequences is made. The number of worked sequences and hence working time is determined by the participant's test performance. Main outcome is the immediate block span (longest sequence correctly reproduced in at least two of three items); subsidiary outcomes are the numbers of correctly and incorrectly reproduced sequences and the number of sequencing errors (sequences including all the blocks of a prescribed sequence, but in the wrong order).
- Cognitrone (COG)—measures selective attention. Subjects have to decide whether a displayed figure is identical with one of four figures shown or not. Working time per item is unlimited and total working time is restricted to 7 min. Main outcomes are the number of reactions and the percentage of incorrect reactions; subsidiary outcomes are both the numbers of correct and incorrect reactions and both the mean times to react correctly and incorrectly.

Statistical analyses

All analyses were performed with the data of the children who completed both test days (complete-case analyses). As outcome measures the parameters of cognitive functioning (main outcomes and subsidiary outcomes) presented in Table 3 were considered. For continuous and discrete interval-scaled variables (WAFA, COG), individual differences of the respective outcomes of both test days (test day 1–test day 2) were compared on the group level (SL–HL vs HL–SL) using the unpaired *t*-test for normally distributed data and the Wilcoxon rank-sum test for

Table 1. Study conduct on 2 days per week (W = Wednesday; T = Thursday) over a period of 6 weeks (1–6) in six school classes (a–f)

Day	W	T	W	T	W	T	W	T	W	T	W	T
Week	1	1	2	2	3	3	4	4	5	5	6	6
Class	a	b	a	b	c	d	c	d	e	f	e	f

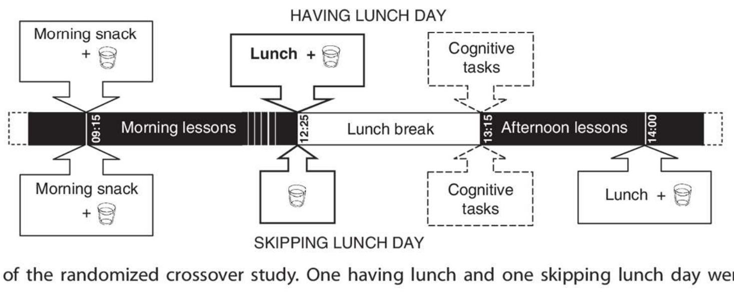

Figure 1. Study schedule of the randomized crossover study. One having lunch and one skipping lunch day were embedded in everyday school life.

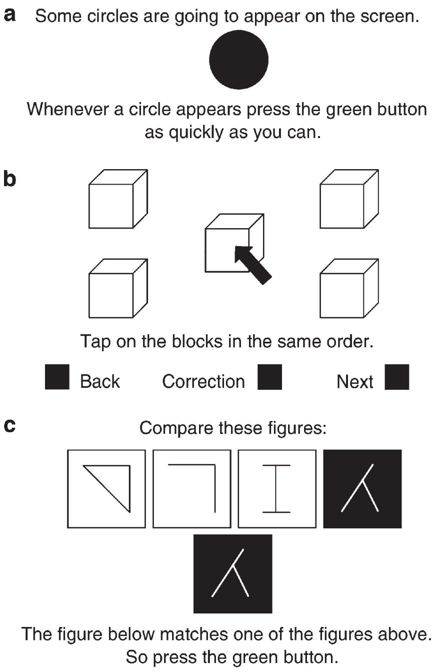

Figure 2. Instruction screens for the applied tasks: Perception and Attention Functions: Alertness (**a**), CORSI Block-Tapping-Test (**b**) and Cognitrone (**c**).

non-normally distributed data. For discrete ordinal-scaled variables (CORSI), treatment effects were analyzed using generalized linear models (PROC GENMOD) with the assumption of a multinomial distribution. As link function, cumulative logit was used in the model. The fixed statement considered treatment, test day and the interaction between treatment and test day. Adjustment for multiple testing had been equated with the Bonferroni procedure. According to the crossover design, we also considered potential carryover effects although these might be irrelevant here, with the carryover effect defined as the persistence of a treatment applied at the first test day in the second test day of treatment.[17] However, no carryover effects were found. The calculation of sample size based on parallel group design revealed that 68 children are needed to detect a difference of 45 ms in the mean reaction time (WAFA Alertness) between the groups SL–HL and HL–SL, with $\alpha = 0.05$ and a power of 0.8. All analyses were performed using the statistical software package SAS 9.1.3 (SAS Institute, Cary, NC, USA). $P < 0.05$ was considered as statistically significant.

RESULTS

Of 116 children with written parental consent, 11 children (9%) dropped out because of illness on one of the test days. The mean age of the study population ($N = 105$) was 12.6 ± 0.6 years; gender distribution was balanced (48% male); 56% of the participants had lunch regularly, that is, consumed lunch at the school refectory by subscription (Table 2). Weight of eaten pasta Bolognese ranged from 75–490 g with a mean (s.d.) value of 333 g (± 99). For visuospatial memory (CORSI) and selective attention (COG), no significant effects of lunch were observed (Table 3). For tonic alertness (WAFA), a significant effect was found with a higher number of omission errors on the skipping day as compared with the lunch day ($P = 0.03$). A greater deviation of reaction time on the skipping lunch day than the having lunch day was observed, but difference was not statistically significant ($P = 0.07$).

Table 2. Characteristics of the study population

	SL–HL (N = 49)	*HL–SL* (N = 56)	*Total* (N = 105)
Age, mean ± s.d., *years*	12.6 ± 0.5	12.6 ± 0.6	12.6 ± 0.6
Male, *n* (%)	21 (43)	29 (52)	50 (48)
Regular lunch[a], *n* (%)	32 (65)	27 (48)	59 (56)

Abbreviations: HL, having lunch day; SL, skipping lunch day. Group S-L skipped lunch during the first period, group L-S skipped lunch during the second period. [a]Defined as consuming lunch at the school refectory by subscription.

We performed an additional analysis considering only participants who had fully adhered to the study protocol (no eating and drinking except for lunch and water) ($N = 86$): the significant effect of lunch skipping on the number of omission errors (WAFA) disappeared (data not shown).

DISCUSSION

In the present crossover study, lunch had no effects on children's short-term cognitive functioning regarding the visuospatial subsystem within the working memory and the selective attention, whereas the data indicate an effect on tonic alertness with a higher number of omission errors and a larger deviation of reaction time on the skipping day as compared with the lunch day. To our knowledge, this is the first study providing initial insights into the effects of lunch *per se* on children's short-term cognitive functioning. Existing studies in children focused on cognitive effects of modifying lunch provision and lunch environment, for example, cafeteria layout.[18,19] However, potential effects of those programs might not only be owing to lunch but also to improvements in children's mood and well-being.

Only within adult studies the effects of lunch on short-term cognitive performance were examined yet, with lunch size and lunch composition primarily considered.[11,20–25] Only three studies compared lunch skipping with lunch.[12–14] The cognitive aspects assessed (for example, perceptual discrimination, sustained attention) were mostly different from ours, making a direct comparison impossible. Smith and Miles[13,14] determined selective attention as we did, but used a Five-Choice Serial Reaction Time Task in a randomized intervention study.[13,14] In contrast to our study using the Cognitrone, they found an effect with the group who skipped lunch being faster than the group who had lunch. Taken together, available studies in adults suggest an adverse effect of having lunch on some aspects of cognitive functioning. In this context, the so-called post-lunch dip, which may be caused by endogenous factors (circadian rhythm) but also by exogenous factors (for example, lunch),[26] has often been discussed. Furthermore, Follenius *et al.*[27] observed a lunch-related cortisol peak,[27] which in turn may be responsible for a decrease in cognitive functioning.[14] However, the results in adults and potential underlying mechanisms are not necessarily applicable to children, as age- and growth-related physiological differences between children and adults exist. A different circadian rhythm and hormonal status in children may be conceivable. Furthermore, during brain development there are several peaks in brain growth with one of those peaks occurring at the age of 12[28] and therefore well within the age range of our sample. Those peaks are characterized by a higher glucose utilization rate of the brain when compared with adults, with a relation to synaptogenesis supposed.[29] Therefore, children's cognitive functioning may be

Table 3. Effects of skipping lunch vs having lunch on selected aspects of cognitive functioning in a crossover study

Parameters of cognitive functioning	(N = 105)						P-*value*
	Skipping lunch			*Having lunch*			
	Median	*25th Percentile*	*75th Percentile*	*Median*	*25th Percentile*	*75th Percentile*	
Alertness							
Mean reaction time, ms	**279**	**256**	**308**	**281**	**254**	**305**	**0.79[a]**
Deviation of reaction time	**84**	**60**	**113**	**77**	**56**	**101**	**0.07[a]**
Omission errors, *n*	0	0	1	0	0	0	0.03[a,b]
Commission errors, *n*	2	1	4	2	0	3	0.61[a]
Visuospatial memory							
Immediate block span, *n*	5	4	5	5	4	5	**0.25[c]**
Correct immediate block span, *n*	10	8	12	10	8	12	0.33[c]
Incorrect immediate block span, *n*	2	1	3	2	1	3	0.70[c]
Sequencing errors, *n*	2	1	3	2	1	3	0.63[c]
Selective attention							
Reactions, *n*	**638**	**574**	**739**	**628**	**561**	**704**	**0.62[a]**
Incorrect reactions, %	**5.3**	**3.4**	**9.3**	**4.7**	**2.6**	**7.7**	**0.11[a]**
Correct reactions, *n*	594	532	670	586	533	656	0.45[d]
Incorrect reactions, *n*	35	19	59	30	14	55	0.13[a]
Mean time correct reactions, s	0.6	0.5	0.7	0.6	0.6	0.7	0.68[a]
Mean time incorrect reactions, s	0.5	0.4	0.6	0.5	0.4	0.6	0.67[a]

Main outcome measures are written in bold. [a]Wilcoxon rank-sum test. [b]With Bonferroni correction no longer significant. [c]Generalized linear models. [d]Two sample *t*-test.

particularly prone to insufficient energy and nutrient supplies due to lunch skipping.

The absence of differences in the selective attention and the visuospatial memory in the present study suggests that there actually might be no effect of skipping lunch in our participants. This possibly could be due to the relatively short fasting period between morning snack and cognitive assessment (4 h), which might be no problem for selective attention and visuospatial memory in healthy, well-nourished children. Regarding cognitive assessment, it may also be possible that the applied test battery of the VTS was not sufficiently sensitive to detect small effects. Furthermore, task selection may have a role, as performance on tasks requiring sustained attention seems to be more attenuated by lunch than performance on shorter tasks requiring selective attention.[30] Last but not least, effect modifiers may have a role (for example, sex). There are experimental studies indicating that sex seems to influence the way breakfast effects cognitive functioning,[31,32] for example, male students but not female students had improved visuospatial memory after eating breakfast in the study from Widenhorn *et al.*[32] The same or a similar effect may also be conceivable for lunch in children. However, in the present study sex-stratified analyses revealed no effects either in boys or in girls.

Regarding alertness the results of the present study might be an indication for 'lapses of attention' in those children who skipped lunch, with 'lapses of attention' operationalized as response omissions and extremely long reaction times.[33] However, these results have to be interpreted with caution, as the effect on omission errors was no longer significant when excluding the children who did not fully adhere to the study protocol and adjusting for multiple testing by Bonferroni correction. Furthermore, for omission errors there are many zero values and less nonzero values, with this frequency distribution possibly having effect on the results of the Wilcoxon rank-sum test.

Several limitations of this study need to be mentioned. First, CogniDO was an open-label study, in which everyone involved knew about group assignment. Second, lunch patterns among study population were different (Table 2): only 56% of the participants had school lunch regularly. According to the teachers the other children brought lunch from home or possibly ate nothing. Third, it is difficult to create familiar, everyday test conditions and to control for potential confounding factors at the same time. Therefore, some children did not fully adhere to the study protocol, in particular did not refrain from eating and drinking as they were told before ($n = 19$). However, excluding those children changed the results; with the significant effect for omission errors disappearing. Fourth, we had no information on the initial values and the course of cognitive functioning as we applied only one cognitive assessment per test day and refrained from baseline determination as well as repeated testing during the afternoon. The reason for this is that children might loose their motivation by going through the tasks for several times, which was emerged from the pilot test.

Strengths of our study are the crossover design eliminating between-patient variations, the homogenous study population in terms of age and the balanced girl-to-boy ratio (Table 2).

The study protocol was thoroughly embedded in children's daily schedule with cognitive tasks performed at the usual beginning of afternoon lessons as this timing enables the transferability of results to everyday school life (Figure 1). Compared with adult studies, which offered a non-standardized test meal or a defined amount of test meal, the participants of the present study were offered a 'quasi-standardized' test lunch *ad libitum* (predefined meal, that is, Pasta Bolognese; free choice regarding the amount of meal components, for example, pasta and sauce). In the study of Smith and Miles[13] nearly all adult participants reported that the non-standardized test meal had been larger than their habitual lunch and the authors suggested that the observed effect of being faster in the Five-Choice Serial Reaction Time Task when skipping compared with having lunch might not be due to test lunch, but rather to a deviation from habitual lunch.[13] Furthermore, the application of a lunch that is popular with children (Pasta Bolognese) guards against a biased lunch effect.

CogniDO allows for the first time an insight into the effects of lunch on children's short-term cognitive functioning. Except for tonic alertness, no differences in the parameters of short-term cognitive functioning were observed between the skipping lunch day and the having lunch day. However, these results have to be interpreted very cautiously. To permit scientifically well-founded conclusions and provide any cognition-related nutritional recommendations for children, more well-designed studies of this type are needed. In the meanwhile, our results should not retard the promotion of lunch as a specifically nutritious meal in an overall balanced diet for children.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

This study was supported by a grant from the Uniscientia Foundation, Vaduz. Thanks to the children, the teachers and the kitchen staff for their participation and cooperation in the CogniDO study. The authors would also like to acknowledge the dedicated field work staff of the CogniDO study. Particular thanks to Professor Dr Axel Schölmerich (Department of Developmental Psychology, Ruhr University Bochum) for valuable comments, to Evgenia Freis (Faculty of Statistics, TU Dortmund University) for statistical consulting during the study planning and to Bernhard Scheffel (PsyExpert e.K., Mannheim, Germany) for advice on application and evaluation of the test battery. The Cognition Intervention Study Dortmund (CogniDO) is registered on clinicaltrials.gov (NCT01401153).

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4 GENERAL DISCUSSION

4.1 Synopsis of research results

67% of the HELENA sample got their lunch at home, followed by those who participated in school meals (26%) and those who had their lunch elsewhere (7%). No statistically significant differences in lunchtime energy intake between the adolescents who usually get their lunch at school, at home or elsewhere were found. With 93-109% lunchtime energy intake was nearly in line with the OMD. However, despite significant differences in lunchtime food intake (except for meat and meat products, eggs, and fruit) between lunch locations, intake of (target) food groups was suboptimal when compared with the OMD at all lunch locations. For drinks, adolescents fulfilled the recommendations by 31-57%, with the highest values for those getting their lunch at home. Median vegetable and potatoe intakes reached 7-17% and 16-41% of the recommendations, respectively, with the highest intakes of vegetables at home and of potatoes at school. The recommendations for fish and fish products were not reached at all, whereas meat intake exceeded the recommendations by 16-39%. For the sweet food group, adolescents who get their lunch at home and those who get their lunch elsewhere highly exceeded the recommendations (417% and 1550% of recommendation, respectively). In contrast, median sweet intake was 0% of the OMD recommendations at school. In contrast to other studies (on a national or regional level), only 0.2% of the HELENA sample (n=893) skipped lunch on school days (Objective I).

A critical evaluation of the literature (for details see chapter 1.3) yielded no studies examining the acute effects of lunch on children's cognitive functioning, which clearly shows that there is a great need for research in this area. Participants of the first randomised crossover study on this issue were 105 schoolchildren. The study showed no significant effects of skipping lunch vs. having lunch (mean ± SD amount 333 g ± 99) on visuospatial memory and selective attention. For tonic alertness, a greater deviation of reaction time after the no lunch condition compared to the lunch condition was found, but difference was not statistically significant (P=.07). Moreover, a significant effect was observed with a higher number of omission errors on the skipping lunch day when compared with the having lunch day (*P*=.03). However, the effect on omission errors was no longer significant when excluding the children who did not fully adhere to the study protocol (n=19) and adjusting for multiple testing (Objective II).

4.2 Objectives

This chapter discusses the findings of the conducted studies in the light of the objectives presented in chapter 2 and their common scientific background (chapter 1). Since this thesis is cumulative, more detailed and specific discussion can be found in the original articles.

4.2.1 Objective I: To describe and evaluate potential differences in lunchtime energy and food intake of adolescents who get their lunch at school, at home or elsewhere

What the lunchtime energy and food intake of European adolescents at different lunch locations look like was considered by a specific data analysis of the HELENA study and described in original article 1 (chapter 3). Especially, insight whether lunchtime energy and food intake is in line with a food-based dietary guideline (OMD) dependent on lunch location was gained.

No significant differences in lunchtime energy intake between adolescents who usually get their lunch at school, at home or elsewhere were observed. This finding on energy intake is not in line with the results of a study of the USDA which showed that food away from home (but also from school) was associated with a higher energy intake when compared to food from home in schoolchildren, especially in the age group of the 13 to 18-year-olds (Mancino, Todd, Guthrie, & Lin, 2010). Methodological factors (e.g. no common definition of lunch location), but also cultural biases may be responsible for the observed differences between European and US data. However, the energy intake levels within the HELENA study sample were similar to those recommended by the OMD, implying that adolescents exhibit low physical activity levels nowadays. The lunch energy intake in HELENA thus seems to be compatible with the current lifestyle habits.

In contrast to lunchtime energy intake in HELENA, lunchtime food intake was not in line with most of the OMD recommendations regardless of lunch location and therefore needs to be rearranged. For example, OMD recommendations were not fulfilled for important food groups such as drinks, vegetables, and potatoes at school. As mentioned in chapter 1.1.3, findings from other European studies also point to an unsatisfactory nutritional quality of school lunches. However, HELENA also indicates several advantages of school lunches compared with the other locations. Thus, adolescents who get their lunch at school consumed much less sweets and more potatoes than adolescents who get their lunch at home or elsewhere. Especially the low intake of the sweet food group at school is interesting. Given that this food group in

HELENA consists to a large part of carbonated/ soft/ isotonic drinks, it may be assumed that sweetened beverages are not as easily available for school lunches as for lunches at home and elsewhere in Europe. This could be a reflection of European school food policies that set restrictions on beverages available or recommended to school children. In line with this, the timely report of the European Commission on national school food policies across Europe showed that most of the countries participating in HELENA (Austria, Belgium, Germany, Hungary, Sweden, and Spain) restrict soft-drink consumption at school specifically for lunch (Storcksdieck, Kardakis, Wollgast, Nelson, & Caldeira, 2014), an activity that is apparently put into lunch practice. Since OMD recommendations for drinks (water and other unsweetened beverages) were not fulfilled at school, another political activity, namely the support of (free) access to water at school in many European countries, does not seem to work just as good. However, whether the intake levels of drinks would even be lower without such activities cannot be clarified in this context. Furthermore, some of the school food policies were introduced when data collection in HELENA had already been closed.

As only little meaningful information on the comparison of school lunches and lunches eaten at home exists one should be cautious in drawing conclusions. Nevertheless, in HELENA there seem to be some advantages of lunch from home when compared with the other locations. Adolescents getting their lunch at home had higher intake levels of unsweetened drinks and vegetables compared to the other groups, although the recommendations for the two food groups were also not fulfilled by the adolescents who get their lunch at home. From a public health perspective, it is interesting that the largest group of HELENA adolescents (67%) usually get their lunch at home.

In HELENA, data suggest that adolescents getting their lunch elsewhere have the unhealthiest lunch pattern, possibly because nearly 40% of them gets their lunch from a fast food restaurant. US children who consumed fast food were characterised by a higher energy intake and poorer diet quality (e.g. more sweetened beverages, fewer vegetables) compared to those who did not (Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004; Paeratakul, Ferdinand, Champagne, Ryan, & Bray, 2003). From a public health perspective, only 7% of the HELENA adolescents fortunately belonged to this group who usually get their lunch elsewhere.

Unlike other studies, the HELENA study was characterised by an almost negligible percentage of ‘lunch skippers’ (0.2 %) (for details see original article 1). Since lunch skipping is often intuitively related to impaired cognitive functioning in schoolchildren, the results from the HELENA study could be interpreted as positive. However, no study has yet examined the effect of skipping lunch vs. having lunch on schoolchildren's cognitive functioning. From adult studies, some evidence suggest negative effects of lunch on aspects of cognitive functioning which cannot be directly applied to children. The CogniDo study examined the association between lunch and cognitive functioning in children (original article 2) and will be discussed in more detail in the following.

4.2.2 Objective II: To examine the impact of skipping lunch vs. having lunch on schoolchildren's short-term cognitive functioning

Whether skipping lunch compared to having lunch influences short-term cognitive functioning of all-day schoolchildren was considered by the original article 2 (chapter 3). Lunch has so far never been examined in relation to short-term cognitive functioning in children. Earlier findings of adult studies suggest that having lunch impairs some aspects of cognitive functioning (Craig et al., 1981; Smith & Miles, 1986a, 1986b). CogniDo, the first study in children, in contrast, did not show any short-term detrimental effects of having lunch (for details see original article 2).

As suggested earlier, a comparison of the findings from CogniDo with results of earlier adult studies is only possible to a limited extent. After rapid brain growth in infancy and early childhood, further peaks in brain growth are found in adolescence around the ages of 12 and 15 years. Furthermore, around the age of 12 years the glucose utilisation rate of the brain still seems to be higher than in adults (for details see chapter 1.2.4). The mean age of the CogniDo sample was 12.6 (SD 0.6) indicating that brain growth might be at one of its peaks. It would therefore be plausible that children's cognitive functioning is particularly susceptible to insufficient energy and nutrient supplies due to skipping lunch. However, both skipping lunch and having lunch did not go along with any relevant adverse effects on cognitive functioning in CogniDo (for details see original article 2). Besides the growth-related and metabolic differences between children and adults, other differences regarding, for example, circadian rhythm or 'chronotype' ('larks' or 'owls', referring to behavioural preferences of morningness and eveningness) and hormonal status may act as effect modifying factors.

Morningness/ eveningness changes across the lifespan with older children and adolescents showing more evening tendencies than younger ones. This evening tendency commonly reverses in the third decade of life and aging is associated with a change toward morningness again (Crowley, 2013). There may be differences, in turn, regarding the chronotype in the likelihood of exhibiting a post-lunch dip. Horne, Brass, and Pettitt (1980) found an obvious post-lunch dip in 'larks', who showed a remarkable decline in performance between noon and 2:00 p.m., which was after lunch for most subjects. 'Owls', in contrast, showed a slight improvement over the same period. These observations might be an explanation for the finding from the CogniDo study where adolescent study participants might exhibit evening tendencies and thus no post-lunch dip, which was suggested for adults to modify the effects of lunch on cognitive functioning. Whether the participants of the CogniDo study show rather evening tendency or rather the contrary could not be determined within the study design. Regarding hormonal status, the association between increased cortisol levels and impaired cognitive performance seen in adults (for details see chapter 1.3), is not necessarily applicable to all other age groups. However, to the best of the knowledge of the author of this thesis, studies that examined this particular aspect in children or adolescents, are lacking.

Regardless whether differences between children and adults exist, task selection may have a role on cognitive test results. Selective attention and tonic alertness as more fundamental processes as well as visuospatial memory might be more stable cognitive functions less effected by nutritional influences than higher-level cognitive aspects (e.g. executive functions). The prefrontal cortex matures late in childhood and goes along with increased abilities in executive functions (Yurgelun-Todd, 2007). Therefore, it can be presumed that executive functions of older children and adolescents might be more influenced by nutritional aspects, such as glucose availability, than fundamental functions. CogniDo Plus, a continuation of the CogniDo study, was conducted in 2013, addressing this specific issue of lunch effects on executive functions (Schröder et al., 2015). The study design and schedule was more or less identical to that of CogniDo, but contrary to CogniDo executive functions (switching, updating, and inhibition) were considered. Furthermore, salivary cortisol measures have been taken before and after lunch (before cognitive assessment). The intention to treat analysis did not show any short-term effects of lunch on executive functions. However, after excluding implausible data lower false alarm rates in the updating function were found after having lunch when compared to skipping lunch. Stratification for postprandial cortisol level showed that the sub-group with a high increase had lower false alarm rates after having lunch while in the sub-group with a low increase the number of false alarms did not change.

Unlike adult studies in this area of research, both children studies indicate that lunch does not have a detrimental effect of lunch on cognitive performance in the early afternoon. It may even be possible, that lunch can positively affect some aspects of cognitive functioning (e.g.

updating). However, to permit scientifically well-founded conclusions, more well-designed studies of this type are needed.

4.3 Methodological considerations

4.3.1 Study populations and designs

Analyses in this thesis were based on a sub-sample of the HELENA study and the first part of the consecutively designed CogniDo study. The HELENA study is a large cross-sectional multi-centre study, which is purely observational and provided the possibility to get a snapshot of the lunch pattern within the HELENA countries across Europe. In contrast, CogniDo is a crossover intervention study, which examined the direct effect of a randomly assigned exposure (lunch) on an outcome (short-term cognitive functioning) under real-life conditions. Therefore, data of this thesis derived from secondary data analyses (HELENA) and an intention to treat analysis (CogniDo).

The sub-sample of the HELENA study included 891 adolescents (47% male) from eight European countries with a median age of 13.3 years. The major advantage of the HELENA study, besides the large sample size, is the strict standardisation of the fieldwork across countries, which prevents immeasurable factors to a great extent that often interfere when comparing results from isolated studies (Moreno et al., 2008). Although the HELENA sample was not fully representative, as discussed in the original article 1, the selection of the study population can be seen as best balance between what is scientifically desirable and what is practically feasible and methodologically justifiable in a large European study (Moreno et al., 2008).

CogniDo included healthy 6th grade students (n=105) of a secondary all-day school in Gelsenkirchen, Germany. This is a population, which is vulnerable to skipping lunch (see chapter 1.1.3), but needs to achieve a high performance during the afternoon lessons. While the study population of this randomised crossover study is inhomogeneous in terms of habitual lunch consumption (only 56% of participants had lunch regularly), it is homogenous in terms of age (12.6±0.6 years). Moreover, with 48% of the participants being male the gender ratio is largely balanced. Even though schools are a favourable setting to reach familiar, everyday test conditions it was difficult to strictly control the children, i.e. prohibit extra food intake between breakfast and lunch. Nevertheless, a high overall rate of 82% participants fully adhering to the study protocol was achieved.

With both studies and their specific characteristics it was possible to appropriately study the underlying research questions of this thesis (see chapter 2). Even though the studies are not (fully) representative, it should be noted that representativeness is of minor importance when describing sample characteristics, as it was the case in the HELENA study, and when examining internal associations between exposure and outcome, as it was the case in CogniDo. Unquestionably, the results cannot be generalised.

4.3.2 Studying lunch in children and adolescents

The studies enclosed in this thesis focused on lunch from completely different perspectives. In the HELENA analysis, lunchtime eating habits of adolescents were described and evaluated against a food-based dietary guideline providing background data on meal pattern. With children of a similar age, the impact of skipping vs. having lunch on short-term cognitive functioning was examined in CogniDo.

HELENA

The HELENA study was originally not designed to assess lunch in particular. However, data were obtained from a self-administered, computerized 24HR, with lunch being explicitly queried as one of six meal occasions. Considering the 24HR approach, the project European Food Consumption Survey Method (EFCOSUM) regarded it as the best tool to get population means and distributions for people aged 10 years and older in different European countries for several reasons: the 24HR is applicable in large European populations of different ethnicity, has a relatively low respondent and interviewer burden, is open-ended, and cost-effective (Biró, Hulshof, Ovesen, Amorim Cruz, & Group, 2002). Moreover, compared to the dietary record method the 24HR occurs after the food consumption, which has less potential for the assessment tool to interfere with the habitual dietary intake (Thompson & Subar, 2013). The main weakness of the 24HR approach relates to the accuracy of people's report of food consumption due to knowledge, memory, and the interview situation (Thompson & Subar, 2013). Self-administered application may be even more problematic, especially among children and adolescents, when compared with an interview-administered application. In order to avoid inaccuracy as far as possible, special techniques were included to allow a detailed description and quantification of foods (Vereecken et al., 2005; Vereecken et al., 2008). First, questions were asked which helped the adolescents to remember their meals (e.g. 'When did you have your meal?' or 'With whom did you have your meal?'). Second, more than 2600 pictures of more than 300 food items were available in order to facilitate more accurate portion size estimations. Third, if appropriate, a text box appears on the screen probing for food items often eaten in combination with other items (e.g. French fries: do not forget mayonnaise/ ketchup!). Finally, both a warning signal was given when extreme amounts were entered and zero values were not accepted. If these situations occurred adolescents were redirected to check and validate the entry. However, with a study population of adolescents issues of motivation and body image need to be considered and might be even more problematic than cognitive abilities to self-report dietary intake, which should be fully developed at this age (Livingstone & Robson, 2000). Hence, miss-reporting in terms of over- and under-reporting would be especially conceivable in adolescents. Indeed, the 24HR used in HELENA was identified to have substantial underreporting bias (Vereecken, Dohogne, Covents, & Maes, 2010). Therefore, only plausible recalls were included in the analyses to overcome the issue of over-/ underreporting (for details see original article 1). Since adolescents may have less knowledge of food preparation (Livingstone & Robson, 2000), there is still the problem that the use of ingredients for food preparation (e.g. oils and fats) might be underestimated.

Information on lunch location was derived from a separate questionnaire in HELENA, which contained a specific question about the place where the adolescents usually get their lunch during the week. Data on the provision of school lunch in the HELENA schools or on the lunch at the 24HR day was unfortunately not available. Therefore, the usual lunch location is not necessarily the same as the lunch location at the recall day. It is possible that adolescents usually go home for lunch, but had lunch at the school canteen or elsewhere at the recall day for any reason, which would distort the results. Since food source rather than location where lunch is usually eaten was of interest in these analyses, both packed lunch and lunch eaten at home were allocated to the home condition. Moreover, lunch location is not uniformly defined between studies making a direct comparison difficult. Studies considering lunch sources often compared lunch eaten at home to lunch eaten outside of home (including restaurants, fast food shops and school canteens) (Burke et al., 2007; Vandevijvere, Lachat, Kolsteren, & Van Oyen, 2009), which is not in line with the HELENA analyses in which restaurants and fast food shops were coded as food from elsewhere and school canteens as food from school. On the other hand, in an US study on lunch all foods available for purchase at school were allocated to foods from school, not only those which were offered as part of school meals (Mancino et al., 2010).

As mentioned in chapter 1.1.3, there is a lack of uniformity regarding school lunch regulations in Europe. Therefore recommendations established in other European countries are not necessarily in line with the OMD recommendations considering typical German meal pattern. Foods that represent only minor parts of lunch in the OMD (e.g. bread and milk) can be used quite differently for lunch in other countries (e.g. Finland, where bread is an integral part of a healthy school lunch). The difficulties of comparing lunch pattern of a European population to recommendations from a single country are a weakness of this analysis and need to be considered when interpreting the data. However, since no common EU lunch recommendation exists, this approach is unavoidable when evaluating adolescent's lunch pattern across Europe. Unique to the OMD is that the concept is meal-based, i.e. the 'official' German reference values for nutrient intake are translated into food-based recommendations resulting in reference intakes for food groups which should be eaten for lunch (or other meals of the day). Moreover, the OMD quantities were specifically re-calculated for adolescents' energy requirements, which make them useful to evaluate food intake in the HELENA adolescents.

CogniDo

Meals represent the way people really eat (see chapter 1.2.5). However, studying meals in dietary intervention studies is complicated for three specific reasons (Mahoney, Taylor, & Kanarek, 2005). First, it is difficult to create a control group or placebo for a meal in order to minimize the confounding effects of research bias (Mahoney, Taylor, & Kanarek, 2005). A control procedure is well realisable in studies considering the cognitive effects of single nutrients, e.g. in form of pills, drinks and powders that are indistinguishable from the placebo (Benton & Stevens, 2008; Grodstein et al., 2013; Haskell et al., 2008; Kennedy et al., 2010; Vazir, Nagalla, Thangiah, Kamasamudram, & Bhattiprolu, 2006). In CogniDo where lunch condition was compared to no lunch condition blinding was impossible. Second, single nutrients (e.g. vitamins, minerals) may produce larger effects than meals and thus are easier to interpret (Mahoney, Taylor, & Kanarek, 2005). Last but not least, as test meal composition usually differs between studies, especially when they are from different countries, study results cannot be easily compared. The way in which lunch affects cognitive performance may depend on characteristics of the test meal such as deviation from habitual lunch and palatability.

In an adult study on the cognitive effects of lunch, almost all participants reported that the test meal had been larger than their habitual lunch. The authors suggested that the observed effect of being better in a Five-Choice Serial Reaction Time Task when skipping compared with having lunch might not be due to test lunch, but rather to a deviation from habitual lunch

(Smith & Miles, 1986b). Another study subsequently investigated this issue with adult participants being categorized as ‘light lunchers’ or ‘heavy lunchers’, depending on their normal lunch habits (Craig & Richardson, 1989). All participants performed a sustained attention task, both before and after a light and heavy lunch, respectively. Indeed, habitual lunch size affected test scores: the largest drop in performance was observed after the consumption of a heavy lunch in persons who usually ate light lunches, whereas the greatest improvement was observed after the consumption of a light lunch in participants who normally ate heavy lunches (Craig & Richardson, 1989). In CogniDo, the test meal was offered *ad libitum* to ensure that children’s self-served portion size is closest to their habitual portion size.

Besides habitual lunch consumption, palatability should be taken into account when evaluating the effect of a meal on cognitive functioning. No studies directly on this topic could be found, but there is the speculation that palatability may affect cognitive performance via increased mood levels (e.g. palatable food-induced increase in endorphins) (Dye & Blundell, 2002). In CogniDo, it was also decided to offer a lunch, which is popular among children (Pasta Bolognese) to ensure that children adhere to the study protocol.

4.3.3 Cognitive assessment

Up to now, the neuropsychological tests that have been used in nutritional research have originally been designed to detect changes in cognitive behaviour in individuals with neurological disorders or traumatic brain injury (Isaacs & Oates, 2008). Therefore, it is still a major challenge to choose appropriate tests that are sensitive enough to detect relatively subtle cognitive changes that could be expected following nutritional interventions. Furthermore, ecological validity needs to be considered, i.e. whether there is a relationship between the test results and the performance on everyday tasks (Spooner & Pachana, 2006). The cognitive aspects assessed in CogniDo reflect fundamental processes having a role in other cognitive functions and everyday activities. The same aspects were also considered in breakfast intervention studies with children (Busch, Taylor, Kanarek, & Holcomb, 2002; Ingwersen, Defeyter, Kennedy, Wesnes, & Scholey, 2007; Mahoney, Taylor, Kanarek, & Samuel, 2005) and lunch intervention studies with adults (Kanarek & Swinney, 1990; Lloyd, Green, & Rogers, 1994; Smith, Kendrick, Maben, & Salmon, 1994; Spring, Maller, Wurtman, Digman, & Cozolino, 1982-1983).

As the advantages of computerized neuropsychological assessment exceed the disadvantages, especially in children who are very familiar with computers nowadays (see chapter 1.2.2), a computerized test battery was used in CogniDo. Children were prepared for each task using a standardised animated instruction phase as well as an error-sensitive practice phase and only if the practice phase was completed successfully the test phase started (for details see original article 2). These standardised procedures minimise the chance that children get lost during testing. Furthermore, children were tested in groups of five to 28 children, which guaranteed that all the children work on the tasks at the same time. However, as there was only one room and limited personnel, the children were tested in a relatively small area, at least the large groups. Therefore, children might have been distracted from the task and this may have influenced the test results.

The practice of re-testing children at regular intervals (Hannan, 2005), as it is the case in a crossover study where each participant serves as his/ her own control, may be a problem. Re-testing is further relevant in nutritional studies to get information on baseline values and the course of cognitive functioning. During re-testing, study participants may remember specific test items, and as the novelty of the tasks is reduced may have already developed certain strategies for solving the tasks (Hannan, 2005). Moreover, as emerged from the pre-test of the CogniDo study, children might lose their motivation by repeating the same tasks several times. That is the reason why instead of conducting a baseline assessment in the morning and a repeated assessment in the afternoon, only one cognitive assessment per test day was applied in CogniDo.

4.4 Public health implications

The findings of this thesis suggest that lunch has neither a positive nor a negative impact on cognitive functioning, at least in healthy schoolchildren aged 12-13 years. As this is the first study of its kind, evidence is not sufficient to use the enhancement of children's cognitive functioning in the early afternoon as an argument for providing a (healthy) lunch at school. Before implementing school lunches for the reason of improving cognitive functioning, more well-designed studies are necessary. In the meantime, lunch should be part of an overall balanced diet, as it provides a considerable part of daily energy and nutrients and may positively affect children's general health in the longer-term.

Overall, the quality of lunchtime food intake of children and adolescents has been found to be unsatisfactory in the school context in the HELENA study as well as other European studies conducted on a national or regional level (Bertin et al., 2012; Rogers et al., 2007). Thus, there is room to improve quality of lunchtime food intake. School probably represents the most promising setting for interventions to improve dietary habits. That is because schools are the most effective way of reaching children and adolescents, including those from all different social backgrounds, but also school staff, families and community members (WHO, 1998).

In order to implement a better quality school lunch as part of promoting a healthy lifestyle two approaches are possible. A structural prevention targets the environment in order to change existing structures, while a behavioural prevention aims to enhance individual knowledge (Table 5).

Table 5 Structural and behavioural prevention to improve dietary habits (modified according to Goldapp et al., 2010)

Definition	Examples
Structural (environmental) prevention targets the environment. The preventive measures refer to spatial, social, economic, and technical aspects of the environment and affect lifestyles and diet, which again has impact on health.	-Access to 'healthy' menu items for lunch -Changes in the lunch environment
Behavioural prevention/ educational activities refers to behaviour and aims to enhance individual knowledge in order to minimise health risks and promote healthy lifestyles.	-Nutrition classes incl. cooking lessons -Posters and pamphlets

Since there may be a synergistic effect by combining structural changes and behavioural campaigns, the two strategies are optimally combined (Sallis, Owen, & Fisher, 2008). Educational activities, such as nutrition classes, may have small impact unless the behavioural change is supported by the access to healthy menu items. Approaches to combine both strategies have been proven to be effective. One intervention, for example, included the installation of water fountains allowing free access to tap water (environmental approach) and, in addition, teachers performed classroom lessons to inform children on the role of water for the human body (behavioural approach) in the intervention schools (Muckelbauer, Libuda, Clausen, Reinehr, & Kersting, 2009). In contrast to control schools, self-reported daily water consumption significantly increased from baseline to follow-up in the intervention schools. Furthermore, after intervention, the incidence of overweight was significantly lower in the intervention group when compared to the control group (Muckelbauer et al., 2009).

Only few, but still 7% of the HELENA adolescents usually got their lunch not at school or at home, but elsewhere (e.g. in fast food restaurants) which seemed to go along with a less healthy food pattern. In contrast, there seemed to be some advantages of lunch from home and lunch from school when each compared with lunch from elsewhere. To encourage children to stay in school or to bring lunch from home to school instead having lunch elsewhere, Beaulieu and Godin (2012a) recently developed and implemented a theory-based programme in a high school of central Canada. The interventions included environmental changes (e.g. additional tables and chairs, microwave ovens) and educational activities (e.g. posters and pamphlets, cooking sessions). A process evaluation showed the usefulness of the interventions. Compared to the control school, both the mean number of days that adolescents stayed in the experimental school during lunchtime and the proportion of adolescents who stayed in the experimental school every day to eat a lunch brought from home or offered by the school cafeteria had increased (Beaulieu & Godin, 2012b). Although the programme was not representative as it was developed in a single school in a specific cultural and environmental context and the results are therefore not necessarily generalisable, the results may be interesting for scientists and programme planers who want to replicate this kind of intervention (Beaulieu & Godin, 2012a). However, staying at school does not necessarily guarantee that a healthy lunch will be consumed (Beaulieu & Godin, 2012a).

To improve lunchtime food intake of those adolescents who cannot be encouraged to eat in school, but have their lunch elsewhere, the fast food lunch alternative is one of the biggest chances, but also proposes the most demanding challenge. Promoting ‘healthy’ foods and beverages in fast food restaurants was already proposed in the US for several times (Koplan, Liverman, & Kraak, 2005; Lee, Mikkelsen, Srikantharajah, & Cohen, 2008). But although educational activities (listing nutrient information on menu) can be combined with environmental activities (offer of affordable and reasonably sized portions) these efforts have not been proven to be successful. However, efforts to improve lunch quality outside the school environment are a bigger problem within the society, which cannot be easily solved.

It is difficult to draw an overall final public health conclusion; however, the combination of structural and behavioral interventions in the school setting may offer a tool to enhance lunch quality. Probably, it can be underpinned by profound, evidence-based lunch recommendations to improve cognitive functioning in the future.

5 CONCLUSION AND PERSPECTIVES

Up to now, relatively little attention has been given to lunch in nutrition research and both HELENA and CogniDo were the first analyses/ studies of their kind.

The HELENA analyses included in this thesis provided the opportunity to examine food consumption at lunchtime in a large sample of European adolescents who get their lunch at school, at home or elsewhere. The results indicate that the adolescents' energy intake was similar to those recommended by the OMD, although their lunchtime food intake was unsatisfactory in the light of the dietary concept regardless of lunch location. It could therefore be concluded that adolescents do not need to eat more or less for lunch, but need to rearrange their lunchtime food pattern. Data suggest that adolescents getting their lunch elsewhere are characterised by the unhealthiest lunch pattern. However, schools, which are a promising setting for interventions to improve dietary habits, do also not seem to use their possibilities to the full to offer a healthy lunch for everyone yet. To improve quality of lunchtime food intake the combination of structural and behavioral interventions may represent a promising tool.

CogniDo provided information on the effects of lunch on schoolchildren's short-term cognitive functioning. In contrast to adult studies, no negative effects of lunch on the cognitive aspects assessed were found, suggesting no post-lunch dip in children. Nevertheless, there is also no relevant beneficial short-term impact of lunch on cognitive functioning in children. As CogniDo was the first study of its kind, more studies of this type are needed to permit scientifically well-founded conclusions. This has already begun to be realised within the framework of CogniDo Plus, the continuation of the CogniDo study. In the future, cognitive assessment instruments that are specifically developed for neurologically intact samples could further improve this kind of research. As an alternative to neuropsychological tasks, an instrument to observe classroom behaviour (e.g. 'on task' and 'off task' behaviour) of schoolchildren during regular lessons (Golley et al., 2010) may be a further step in examining the effects of lunch on children's academic performance. Factors such as habitual lunch consumption and biorhythm should be taken into account as they may modify the effect of lunch.

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7 APPENDIX

7.1 **List of publications** (besides the original articles included in this thesis)

7.1.1 Articles in international and national journals

- Terschlüsen, A. M., **Müller, K.**, Williger, K. & Kersting, M. (2010). Der Einfluss von Mahlzeiten, Nährstoffen und Flüssigkeit auf die kognitive Leistungsfähigkeit bei Kindern. *Ernährungs Umschau, 57* (6), 302–307.
- **Müller, K.**, Libuda, L., Terschlüsen, A. M. & Kersting, M. (2013). A review of the effects of lunch on adults' short-term cognitive functioning. *Canadian Journal of Dietetic Practice and Research, 74* (4), 181-188.
- Schröder, M., **Müller, K.**, Falkenstein, M., Stehle, P., Kersting, M. & Libuda, L. (2015). Short-term effects of lunch on children's executive functioning: the randomized crossover Cognition Intervention Study Dortmund PLUS (CogniDo PLUS). *Physiology & Behavior, 152* (Pt A), 307-314.
- Libuda, L., Schröder, M., **Müller, K.** & Kersting, M. (2015). Mittagessen in der Schule – macht es Kinder schlau oder müde? *Pädiatrische Praxis, 84* (4), 647–665.

7.1.2 Presentations

- **Müller, K.**, Libuda, L., Gawehn, N., Drossard, C. & Kersting, M. (2012). Effect of lunch vs. lunch skipping on children's short-term cognitive function - results of the Cognition Intervention Study Dortmund (CogniDo). 49. Wissenschaftlicher Kongress der Deutschen Gesellschaft für Ernährung, Freising-Weihenstephan. *Proceedings of the Nutrition Society, 17*, 80 [poster].
- **Müller, K.**, Libuda, L., Diethelm, K., Huybrechts, I., González-Gross, M. & Kersting, M. (2013). Lunch at school, at home or elsewhere: where do adolescents get it and what do they eat? - Results of the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study. 46th Annual Meeting of the European Society for Paediatric Gastroenterology, Hepatology and Nutrition, London, 206 [poster].
- **Müller, K.**, Libuda L, Diethelm, K., Gonzaléz-Gross, M. & Kersting, M. (2013). Mittäglicher Lebensmittelverzehr bei europäischen Jugendlichen in Abhängigkeit vom Ort der Mahlzeitenbeschaffung: Ergebnisse der HELENA Studie. 50.

Wissenschaftlicher Kongress der Deutschen Gesellschaft für Ernährung, Bonn. *Proceedings of the Nutrition Society, 18*, 31 [oral presentation].