PLANNING SPACE VERSUS PLANNING TIME:

ANALYSIS OF PLANNING ACROSS CONTEXTS

By

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ABSTRACT OF THE DISSERTATION

Planning space versus planning time: Analysis of planning across contexts

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This study investigated the contribution of task constraints to planning processes and outcomes across four tasks which contained varying numbers of spatial and temporal constraints. Verbal protocols were obtained during forty-five young adults' planning of the four tasks. Participants' conceptualizations in terms of space or time, and their focus on sequencing task elements during planning were clearly related to the spatial, temporal and order constraints in the tasks. Participants were very consistent in the degree to which they focused on time and the amount of verbalizations across tasks, and they were somewhat consistent in their focus on sequencing. They were not consistent in their focus on space. Of the planning outcomes investigated, constraint violations on tasks were related to the proportion of implicit constraints, spatial and temporal efficiency were related to spatial and temporal constraints, and total verbalizations were related total constraints in the tasks. Individual participants' planning outcomes were not related across tasks. The degree to which participants focused on location during planning of a task with mostly spatial constraints was related to spatial efficiency of their plan, this relationship was not seen in a task with spatial and temporal constraints. Various cognitive abilities of were measured, verbal and visuospatial working memory, verbal and nonverbal fluency, processing speed, updating, shifting and inhibition. One measure of visuospatial memory as well as nonverbal fluency was related to the degree to which participants focused on sequencing actions. The results indicate that planning processes

are somewhat general, and that planning processes and outcomes vary with constraints contained in planning tasks. It is suggested that conceptualizing planning tasks in terms of constraints allows for valuable comparison across tasks.

several years ago during a brief conversation (which I am pretty sure he does not

remember). "Look at what they're doing" he told me; the current project is my attempt to

follow this advice.

Table of Contents

List of Tables

List of Figures

Planning space versus planning time: Analysis of planning skills across contexts

Planning is an activity most humans engage in daily over a broad range of contexts. One plans what to eat at the next meal, which program to watch on the television the coming evening, or which route to take for doing one's errands. Plans vary in temporal scope and plan complexity, and planning a party, planning a move to another house, planning a research program or planning for retirement are all examples of plans that span a larger time period or have more elements.

In the following I will show that this ubiquitous human activity of planning has been studied by a host of researchers with very diverse interests and goals, who employ different levels of description for planning, and who differ in their conceptions of planning. In addition these researchers use a number of tasks to study planning which differ in the knowledge base and the stages of planning required to complete the tasks and the level of specification of the task constraints and goal states. On top of this, researchers use different ways of scoring planning performance, some using planning process measures, others using planning outcome measures. In spite of all these differences between research projects, findings are usually treated as generalizable to all planning endeavors, and planning is treated as a general skill. If this were the case, people's planning performance across these different tasks should be related, but the few studies that have investigated this issue show few relationships between planning across tasks. The current study investigates the extent to which the differences in task constraints between tasks contribute to this difference in planning performance across tasks.

Diversity of planning research

Planning has been studied extensively by psychologists with a wide range of interests. Clinicians are interested in the problems with planning daily activities that beset those with frontal lobe injuries, and are concerned with the anatomical localization of lesions that lead to these planning difficulties, as well as issues of rehabilitation (Carlin et al., 2000; Goel & Grafman, 1995; Gouveia, Brucki, Malheiros, & Bueno, 2007; Pentland, Todd, & Anderson, 1998). Neuropsychologists are similarly concerned with anatomical localization of planning as part of a more general quest to localize cognitive functions (Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Goel & Grafman, 2000; Morris, Ahmed, Syed, & Toone, 1993). Cognitive psychologists are interested in planning as a 'higher' cognitive function, that requires some combination of memory, attention, and executive control (Gilhooly, Wynn, Philips, Logie, & Della Sala, 2002; Kliegel, Martin, McDaniel, & Einstein, 2002; Martin & Ewert, 1997). Planning has also received much attention from those in the field of artificial intelligence, by virtue of the fact that it is a 'higher' cognitive function, and a challenging function to model (Hammond, 1990; Hayes-Roth & Hayes-Roth, 1979). And given the importance of planning in daily life, developmental psychologists have investigated how planning ability comes online in children and declines in old age (Friedman & Scholnick, 1997; Friedman, Scholnick, & Cocking, 1987; Phillips, MacLeod, & Kliegel, 2005).

Levels of description

The different interests of researchers studying planning result in preferences for different levels of description and explanation of the activity. One can describe and/or explain planning task performance on any of these four levels (see Figure 1):

1. Observable behavior, e.g. moves in a task, eye movements, RTs, latency to certain behaviors, verbalizations during a task.

2. Indirectly observable physiological changes: mostly regional blood flow changes in PET and fMRI observations, or electrical activations in EEGs or ERP measurements. The anatomical localization of the physiological changes is usually the primary interest.

3. Level of hypothetical task operations: this is the level of cognitive operations inferred from task analysis and behaviors, e.g. recognition of planning situation, generating plan elements, evaluating the plan, monitoring plan execution. This level of description is very much bound to the task.

4. Level of hypothetical constructs and functions, e.g. loading of task information into working memory, retrieval or activation of information in long term memory, shifting attention.

Although there are two general axes of division between the levels of description, the distinctions they create are not symmetrical, i.e. the distinction between observable behavior and indirectly observable physiological changes on the one hand is not symmetrical with the distinction between hypothetical operations and hypothetical constructs and functions on the other hand, similarly between behaviors and task operations versus physiological changes and constructs/functions.

Elements on any of the levels can theoretically be mapped onto elements of any of the other levels, and this is indeed what a lot of studies aim to achieve.

Researchers generally concentrate on one or two of these levels in their studies. For example Carlin and colleagues (2000) compared performance on the Tower of

London by patients with frontal lobe dementia and patients with focal frontal lobe

lesions. The performance of patients with focal lesions suggested difficulties with plan

execution, whereas that of those with frontal lobe dementia implied problems with both

plan development and execution. The flow is from difference in histopathology, to a

behavioral difference, to a difference in task operations. Contrast this with a study by

Kliegel and colleagues (2002) who investigated prospective memory by having

participants plan (form an intention) how to perform a task, do several intervening tasks

and then execute their plan at a set point. They concluded that planning and cognitive

flexibility, conceived as types of executive functions, were especially good predictors of

prospective memory. Most of the analysis in this study is on the level of operations and

constructs.

It is important to be clear on which level of description a research project is

operating, especially for the hypothetical descriptions, in order to judge the

commensurability of findings and claims.

Conceptions of planning

Apart from the levels on which they describe and seek to explain planning

performance, researchers also seem to differ in their conception of planning. Planning

gained attention in the '60's after Miller, Galanter and Pribram (1960) posited

hierarchically organized plans as the intermediary between cognition and action, guiding

all human action. This conception of planning has a very broad scope, as on this view

plans are involved in virtually all human action, and 'planning' includes all processes

sequencing future-oriented operations. Newell and Simon (1972) presented planning and

problem solving as a "search through a space of connected problem states, with the

efficiency of the search improved by using a range of different heuristics to think

forwards from the given information of a problem and backwards from the goal of a

problem" (Ward & Morris, 2005, p. 3). This was an extremely influential view of

planning when cognitive psychologists were mostly interested in information processing.

Another conception of planning from the 70's is that of Schank and Abelson (1977) who

presented plans as a storage form for general knowledge, defined as "a series of projected

actions to realize a goal" (p. 71). Planning for them involves searching through stored

plans, and using an earlier plan or adapting one to the current circumstances.

In contemporary research planning is mostly associated with executive functions

or executive control. There are two views on the relationship between planning and the

'executive'. In one, planning is conceived of as a type of activity requiring executive

control, and therefore an indirect measure of executive control. In the other view,

planning *is* an executive function.

All these conceptions of planning are not necessarily exclusive of each other. The

Newell and Simon account of planning mostly describes the task operations level. Schank

and Abelson's planning is also mostly on the level of task operations, but is concerned

with search for plans, rather than creation of new plans. One can think of these as

complementary endeavors. The view of planning as a complex skill which requires

executive control and therefore treats planning as a measure of executive control is also

compatible with the two task operation conceptions. In effect it links the task operations

level with the construct and function level. However, the idea of planning as an executive

function itself does not combine well with the other conceptions. One can think of a

'look-ahead' or 'anticipation' part of planning that is as abstract as 'shifting' or

'updating', but a description of planning that combines Newell and Simon's planning in novel situations and Schank and Abelson's plan construction with the help of previous plans is too complex to be just one executive function. Miller, Galanter and Pribram's description of planning is not useful for a different reason: it is too broad to allow meaningful investigations. When 'planning' covers hammering as well as planning retirement, your conception covers too wide a range of activities to be useful. Although the work in which this view was presented is much cited, the conception of planning itself is not evident in current research. In all then, the conceptions of planning are mostly complementary, either looking at different types of planning stage or focused on a different level of description. This points again to the importance of keeping in mind at which level of description research on planning is situated.

Planning tasks – types

Apart from differences in the levels of description, and to some extent, conceptions of planning, the planning tasks that are used in research vary. I will first give a brief description of these tasks and then discuss some differences between them. From the tradition of Newell and Simon's research into planning and problem solving comes the most popular type of planning task by far: the Tower tasks. Initially the Tower of Hanoi (TOH) (Simon, 1975) was used, in which five disks of decreasing size are moved across three pegs from a starting state to a goal state in accordance with rules constraining disk movement. Shallice and McCarthy (see Shallice, 1982) devised a variant, the Tower of London (TOL), in which the three pegs are of decreasing size, and in which there are only three same-sized, colored beads, but again the disks are moved according to rules constraining movement. Recently a five-disk version of the TOL

(Ward & Allport, 1997) has become somewhat popular, in which the disks are of equal size, and the pegs of equal height. The Tower tasks are thought to be 'look-ahead' problem solving tasks (Shallice, 1982). The TOL allows for a graded set of tasks of variable difficulty, and the 5-disk TOL increases the possible problem set.

Hayes-Roth and Hayes-Roth (1979) were the source of a different type of planning tasks, often called 'errand running tasks'. Their original task involved presenting participants with the map of a town (see Figure 3) and a list of errands. Participants had to plan which errands they were going to accomplish, and indicate in which order and via which route they planned to do this. Other tasks of this type are the grocery planning task used by Gauvain and Rogoff (1989), the chore-scheduling task by Pea and Hawkins (1987), the errand running task by Dreher and Oerter (1987), the errand running task by Burgess, Simons, Coates and Channon (2005) and the Plan-A-Day task designed by Funke and Krüger (1995).

An interesting variation of this type of task is the Multiple Errands Task (MET) (Shallice & Burgess, 1991). The MET is an errand running task which is carried out in a real shopping mall rather than a laboratory, although a shorter version and a hospital version have also been developed (Alderman, Burgess, Knight, & Henman, 2003; Knight, Alderman, & Burgess, 2002). In the original MET the participants were given money and eight tasks to complete, six of which were simple (buy a loaf of brown bread for example), the seventh required them to be in a certain place 15 minutes after the start of the task, and the eighth of which required that they gather four pieces of information and write them on a postcard (e.g. the price of a pound of tomatoes). The MET was designed to test for dysexecutive behaviors in frontal lobe patients.

The Tower tasks and errand running tasks are by far the most common tasks used to study planning, but there are a number of other tasks as well. A relatively recent task is the Six Elements Task (SET) which is a carried out in a laboratory, and which was also designed by Shallice and Burgess (1991) to test patients with frontal lobe injuries. Participants are presented with three activities, each of which has an A-part and a B-part, for a total of six 'elements'. The first activity is one of dictating into a tape-recorder two different items e.g. 'describe the trip to the laboratory' for the A-part and 'describe where you are going after taking part in this study' for the B-part. The other activities are completing arithmetic problems and writing down the names of items depicted in booklets with simple line-drawings (with an A-booklet and B-booklet provided for both these tasks). The participants have 15 minutes to complete as much of each of these tasks as they can, although they are told they will not be able to finish everything. They are instructed to try to do at least something from each of the six parts and they are not allowed to do parts A and B of the same task one after the other. Frontal lobe patients perform more poorly than controls on both the SET and the MET, in spite of normal performance on the Tower tasks (Shallice & Burgess, 1991).

There are other planning tasks that have been used to study planning, mostly tasks invented for the purpose of that particular study, and therefore employed only once. Goel, Grafman, Tajik and Danto (1997) used a financial planning task, Wallner (1996) looked at a social planning task, MacLeod (2001) used a party planning task and Mayhew (2004) used a schoolwork scheduling task.

Planning tasks – differences

(a) Knowledge base or ecological validity of cover story

The main difference between the Tower tasks and the errand running tasks is that the Tower tasks require no real-world knowledge to be solved. The task is therefore presumed to have the same novelty for all participants, which means differences in experience and general knowledge between subjects are controlled, and participants are compared solely on their 'domain-independent' planning ability. In the errand running tasks, on the other hand, experience with, knowledge about and preference for the various elements of the task could lead to changes in task performance that are not due to better planning *per se*. In the grocery store planning task (Gauvain & Rogoff, 1989), knowledge about the category structure of grocery stores leads to more efficient search strategies; in the errand running task (Hayes-Roth & Hayes-Roth, 1979) knowledge about times required for various errands can lead to more efficient choices; and in the errand running task by Burgess et al. (2005) a differential preference between males and females for certain stores was shown to lead to slightly more efficient planning for males.

There are a number of studies that show that planning performance actually improves when the task is cast in a 'real world' context. Klahr and Robinson (1981) found that with certain changes in the presentation format, 4-, 5- and 6-year-old children who normally cannot do 2- and 3-move versions of the TOH (Piaget, 1976, cited in Klahr and Robinson, 1981), were able to complete these successfully. The changes in presentation format included having a goal state available during the task, changing the disks to differently-colored containers placed upside down on the pegs (thereby externalizing the task constraint of no larger disks on top of smaller disks, and individuating the containers by size as well as color). Both of these changes relieve the load on working memory. They also gave the task a cover story with monkey families

(big yellow daddy, medium blue mommy, and little red baby) jumping from tree to tree, and a copycat monkey family that wants to be like the goal state family. The combination of a lighter load on working memory, and an understandable cover story were enough to improve performance in these young children, although it is unknown how much of the improvement was due to each these factors. Kliegel, Martin, McDaniel and Phillips (2007) specifically tested the effect of cover stories in young and old adults. They used structurally identical errand tasks, one a normal shopping trip, the other an analogous errand round in space. The errand of withdrawing money from the bank to pay the electric bill in the real world was analogous to withdrawing gold from planet B to pay one's taxes on planet A in the unfamiliar setting, for example. Kliegel and colleagues found that there was no difference in planning performance between older and younger adults on the real world errand task, but older adults performed worse on the space errand task. They speculated that older adults were able to compensate for the measured decrease in cognitive abilities (processing speed and inhibition) in the real world errand task, but not in the space errand task. It appears then that planning performance may actually improve when experience, knowledge and preferences from familiar contexts can be brought to bear on planning tasks.

This difference between the Tower tasks and errand running tasks can also be cast as a difference in 'ecological validity' of the planning tasks. The generalizability of research findings to performance outside the laboratory is normally considered desirable. One of the sources of generalizability is the degree to which the planning task is representative of or similar to planning situations in real life. The Tower tasks have some problems in this regard, as it is not obvious which planning tasks in real life resemble the

Tower tasks. In contrast the cover stories for the errand running tasks are very familiar. The SET is an interesting hybrid in this regard. The task does not resemble any real life planning situation, but the elements that are to be planned (arithmetic, narration, picture identification) are familiar, and participants can draw on knowledge of these everyday activities while planning. In this respect it may be similar to the monkey cover story in the study by Klahr and Robinson (1981).

In short, planning tasks vary in the extent to which they require 'external' knowledge, and this can lead to variations in task performance that are not due to better planning in and of itself.

(b) Stages of planning

Another way in which planning tasks can be similar to real-life planning situations is the planning stages that are required. In analogy to the stages of problem solving, planning can be said to involve representation of the 'problem', setting a goal, deciding to plan, constructing a plan, followed by execution, monitoring and evaluation of the plan (Scholnick & Friedman, 1987; Scholnick & Friedman, 1993; Scholnick, Friedman, & Wallner-Allen, 1997). For tasks used in research, representation of the planning 'problem' and the setting of a goal is a function of the task specification. Which remaining stages of planning are required by the planning task varies. The Tower tasks, and the SET usually involve all stages of planning, and the plan that is constructed is usually carried out immediately, resulting in some iterations of plan construction, execution and monitoring. An alternative way of administering the Tower tasks is to ask participants to plan their moves in advance of actually moving the disks, which allows for

a separation of the plan construction and execution and monitoring phases. The stages of the SET can be separated in a similar manner.

Most of the laboratory errand running tasks only include the plan construction stage of planning. The grocery shopping task (Gauvain & Rogoff, 1989) is an exception, in that the children actually move a model shopper through the grocery store. The MET is very different again, in that it is actually carried out in a shopping mall, and includes all stages of planning.

When the stage of executing the plan is included in the planning task, plan construction is often provisional. During plan execution changes can be made to the constructed plan when further considerations or constraints arise (an accident on the chosen route, resulting in a delay and forced detour and the construction of an alternative plan for the order of errands for example). Alternate moves or elements may have to be added at that stage. Laboratory errand running tasks do not allow for this and are therefore less similar to real life, or 'ecologically valid' than the Tower tasks.

(c) Number and specification of task parameters

Another way in which planning tasks can be more or less similar to real-life planning situations is in the level of specification of the task parameters. Real-life planning problems often lack specification of the goal (or even the start) state, and require deduction of constraints and 'allowable' moves, which makes many real-life planning situations so-called 'ill-structured' problems (Ormerod, 2005). An important part of planning skill is the ability to recognize the implicit constraints in tasks. In the Tower tasks the start state and the goal state, as well as movement constraints are clearly specified, making the Tower tasks 'well-structured' problems, which don't call on the

ability to infer constraints or decide when the goal is reached. The SET is also well-structured. In this respect Tower tasks and the SET are not representative of real-life planning situations, and therefore not 'ecologically valid'.

Errand running tasks, on the other hand, tend to resemble real-life situations in being less well-structured. The goal state is not clearly specified, and some of the constraints have to be deduced from the task presentation. This makes them more 'ecologically valid' than the Tower tasks in this respect.

Apart from the level of specification of the task parameters, the explicit or implicit nature of the constraints in the task, there can be differences in the number of elements and constraints inherent in a task. This is not a difference between types of tasks as much as between individual tasks. It is clear that these factors can constitute a large difference to the complexity and therefore presumably, the difficulty of a task. A task with seven plan elements, three implicit order constraints, five explicit spatial constraints, and four implicit time constraints is going to require more planning than a task with seven plan elements, one explicit time constraint, an explicit order constraint, and no spatial, or resource constraints.

These differences in the number, the implicit or explicit nature, as well as the type of constraints could conceivably result in a large difference in planning performance which has largely gone unexplored in planning research.

(d) Scoring of tasks

Another difference between studies of planning that is not often highlighted is the difference in scoring of planning performance. In general there are two types of measure. One type looks at planning processes: either the amount, the quality or the content of

planning in the plan construction stage. Another type of measure looks at planning outcomes, and tries to get at the quality of the final plan.

When the tower tasks are administered with a separate plan construction and execution phase, the times required for both can be measured; these are quantitative rather than evaluative measures, as a long duration of planning processes does not necessarily mean that these are good or efficient planning processes. The execution of the plan can be scored on efficiency of the move sequence (total number of moves minus the minimum number of moves) and the number of rule breaks or constraint violations. The same is the case for errand running tasks, although it is often the route efficiency that is used as a plan outcome measure, rather than constraint violations. Plan outcome measures are evaluative.

When different studies use different measures the results are hard to compare. Although both inefficient routes or move sequences and constraint violations are signs of bad planning, they show different problems. An inefficient route can be due to not appreciating the basis for sequencing the errands, but it can also be due to some preference. For example, in Burgess and colleagues (2005) females were found to choose an inefficient route because they generally preferred buying an item on the errand list at a superstore rather than a hardware store. Constraint violations can be due to forgetting the constraints, or paying insufficient attention to them.

When looking at results of planning studies it is important to consider whether planning process or planning outcome measures were used and how these measures were quantified.

Planning as a general skill

The preceding sections have shown that there are many differences between studies of planning, what with differences in levels of description and explanation, and conceptions of planning, as well as between the tasks used to study planning, and the scoring of those tasks. Given this diversity in planning research, it is interesting that most studies treat planning as if it were a in some sense a general skill or function. This is mostly implicit, by stating in some form that the study shows "such and so" about planning. For example: "These results suggest that the abstract plan level may be the optimal level for encoding goals in order to maximize later recognition of a wide variety of opportunities to achieve these goals" (Patalano & Seifert, 1997, p. 28); "Our results give moderate support to the conceptualization of planning development as a protracted process" (Parrila, Aysto, & Das, 1994, p. 223); "We have suggested that planning development consists of acquiring a new planning skill, specifically that of partial-order plan representations, as well as the knowledge of when to use it" (Rattermann, Spector, Grafman, Levin, & Harward, 2001, p. 968); "The present study has documented residual deficits in planning ability, response speed, and ability to formulate strategies in adolescents with a history of severe head injury" (Pentland et al., 1998, p. 315). These are all fine studies, and lifting these statements out of their context in discussion sections would be highly unfair if my primary aim were criticism rather than the illustration of a commonly held assumption. The assumption is that the planning skill that goes into solving Tower tasks is pretty much the same as the planning skill that goes into errand running which is pretty much the same as the planning skill that goes into any other planning task. This assumption can be expressed as 'what you do when you solve a

Tower task is in some sense the same as what you do when you plan errands' and one can argue that it follows that a person who is good at one type of planning task will also be good at any other type of planning task.

Scholnick and colleagues (Scholnick & Friedman, 1993; Scholnick et al., 1997; Wallner, 1996) have argued to the contrary that given the many contextual factors that are known to influence planning at the various stages of the planning process, in addition to the quite different demands that different planning tasks make on the planner, it is it extremely likely that planning performance by any one individual will differ among planning tasks.

There are very few studies that directly compare the same participants' performance on different planning tasks. Wallner (1996) studied the performance of 7-year-olds on the TOH, an errand running task, and a social planning task (planning how to share a toy, planning how to enter a game). She found that the TOH performance (measuring completed problems) correlated with route efficiency in the grocery store but not with the amount of advance planning (advance scanning, advance planning time) carried out prior to moving the shopper around the grocery store (in effect, prior to executing a plan). Advance planning was significantly related to route efficiency (p. 79), but not to TOH performance. There was no correlation at all between TOH and the social planning task, or between either of the measures on the errand running task and the social planning task.

MacLeod (2001) used a cocktail party planning task and compared the constraint violation scores on this task with the TOL and the SET in 96 participants (young, middle-aged and old age groups). In the cocktail planning task, participants are given a list of 19

errands that need to be accomplished in 7½ hours by three friends. The participants are given a map with walking and driving distances. This task involves dividing the errands over the three friends, and constructing optimal sequences for each of them. Given that the TOL, SET and cocktail party tasks are supposedly three planning tasks, she found remarkably few relationships between performance on these tasks. She found that those who took longer in the move phase of the TOL (i.e. time for the execution of the TOL plan) had more errors or constraint violations in the cocktail party planning (Phillips et al., 2005). Other than that there were no relationships between any measures on the SET, TOL or party planning.

Kliegel and colleagues (2002) used the SET to test a model of prospective memory, and altered it so that the participant had to formulate an explicit plan and dictate this plan into a tape recorder (the dictation part of the SET was changed to a word/spelling choice set of tasks). Between dictation of the explicit plan and execution of the plan the participants completed a traditional color-word version of the Stroop, and completed the Plan-A-Day task (a computerized errand running task originated by Funke and Krüger, 1995), and were then allowed to execute the plan. The scoring of the SET plan was based on numbers of times that constraints, reasoning for sequence decisions were mentioned as well as the number of executable elements in the plan. Participants' score for this planning process measure was correlated with scores on the Plan-A-Day task and non-verbal fluency. It was not correlated with participants' scores on the TOL.

Burgess also reports a direct comparison between planning tasks (Burgess et al., 2005), in this case an errand running task and a party planning task. In the errand running task participants are provided with a map (see Figure 4) and told that they are catching a

bus to go and feed ducks at the village pond. They are then given 4 things to do and told to bear some things in mind, and the participants have to 'learn' the scenario and the rules and constraints before they plan. The task is slightly different from other errand running tasks in that the scenario has to be 'learned' and that it has a number of implicit constraints, such as the absence of a pen to write the birthday card that needs to be sent, and the absence of something to feed the ducks with. Unfortunately the report does not mention how the task was scored, nor does it give much information on the party planning task which is 'similar in the amount of information that had to be learnt; the numbers of constraints and rules of the situation that had to be learnt; the numbers of constraints and rules of the situation with which they were faced, and the format of the situation' (p. 220). Participants were also administered a verbal memory task. After removing the memory variance there was no relationship between performance on the errand running and party planning tasks. The study was repeated, substituting a nonverbal memory task for the verbal one, but the results were the same: after removing the memory variance, no relationship between performance on the planning tasks.

The last study that explicitly compared different planning tasks was Mayhew (2004). Elementary school children's performance was compared on an errand running task (the grocery store planning task by Gauvain and Rogoff, 1989) and a schoolwork scheduling task. In the latter task, which was devised for the study, children were provided with a scheduling grid for the school week and a list of school tasks that they normally planned for a school week, and asked to plan when they would complete which tasks. For both tasks plan process quality scores as well as planning outcome scores were computed. In the case of the grocery store the plan outcome was the route efficiency, in

the case of the school week planning task an indirect measure of plan outcome was used: the average of ten weeks' measurements of percentage school week work completed by the end of the Wednesday. For both tasks the planning process quality score was correlated with the planning outcome score ($r = .56$, $p < .01$ and $r = .57$, $p < .01$), however the planning process quality scores for the two tasks were unrelated ($r = -.01$), as were the outcome scores ($r = .16$). The findings of these few studies comparing planning tasks are summarized in Table 1.

In the table various tasks have been categorized together, although it is indicated between which measures relationships were investigated. The tower tasks are grouped together, as are errand running tasks for which maps are an essential part of the task presentation (i.e. the grocery shopping task and the PAD). The cocktail party planning task, although it nominally is an errand running task, requires sequencing errands on the basis of duration and other non-spatial constraints, and is therefore grouped with the school work scheduling task. The tasks described by Burgess et al. (2005) are not included because of insufficient information on the party planning task mentioned.

It is clear from this table that few as the studies comparing planning tasks are, the relationships found between planning tasks are even fewer. In total two relationships are found. The first is between a planning outcome on a Tower task and a planning outcome (route efficiency) on the grocery store task. Both tasks include a plan execution component, and both measures are outcome measures. The tasks differ in many ways, the Tower task does not require external knowledge, whereas the grocery store task does, the numbers of elements between the tasks are different, the basis for sequencing the elements differs, and the numbers and types of constraints are different. The other

relationship found is between SET planning process and PAD planning outcome, one task has an execution component, the other does not, one uses a planning process measure and the other a planning outcome measure and one has an ecologically valid cover story, the other does not, although it must be noted that the components of the SET are all common tasks such as arithmetic. These tasks differ in the numbers of elements, the types and number of constraints, the stimulus presentation, and the basis for efficient sequencing of the elements.

The evidence from these studies together suggests that the quality of planning processes people show on one task bears very little relationship to the quality they show on another task, and that the same is the case for their planning outcomes. These differences could be due to any of a host of differences between the tasks that were compared, for example the differences in the types of tasks, and the difference in the knowledge base required, or the stages of planning required, or the number and specification of the task parameters (elements, start and goal states and constraints), as well as the scoring of these tasks.

Current study

It appears to be high time for a more systematic look at performance on different planning tasks. It is the aim of the current study to investigate the contribution of various types of constraints to differences in both planning processes and planning outcomes across four different tasks. These comparisons are situated at the level of behavior and task operations.

This study shares the assumption that there is something in common by virtue of which planning errands, planning free time, and planning when to do which tasks are

called 'planning'. In all these cases 'planning' refers to 'the cognitive activity of deliberate sequencing of immediate and/or future actions in accordance with constraints in order to achieve some goal'. This definition excludes motor planning, and illustrates the close affinity between problem solving and planning. It also squarely positions that which is in common across planning tasks on the task operations level, and is therefore mute on the subject of how the task operations map onto constructs and functions on the concomitant level. The definition leaves open, on the task level, the numbers of actions, temporal scope, numbers and types of constraints, and type and specificity of the goal involved in any one planning undertaking. Any situation in which planning takes place has parameters that fill these open slots.

The main goal of the current study was to investigate whether it is the way that the parameter slots are filled that determines performance on planning tasks. It is expected that differences in the task constraints will contribute to differences in planning processes and planning outcomes.

In comparing performance on different planning tasks, the current study sought to keep all but a limited number of task parameters the same. Performance on four planning tasks was compared: all laboratory tasks with real-life cover stories and therefore tapping into experience, knowledge and preferences for the domains chosen. All four tasks only involved plan construction and were relatively ill-structured, in that the participants decided when they had constructed a plan that met the constraints.

The main difference between the four tasks in the study was a differing combination of spatial, temporal and order constraints. Two of the tasks had a large number of spatial constraints and included a map as stimulus material with the result that

spatial efficiency was an important sequencing principle. One of these tasks had mostly spatial constraints, the second had both spatial and temporal constraints (these tasks will be referred to as the spatial and the spatial-temporal tasks.) The other two tasks had mostly temporal constraints and involved sequencing actions in time only, although one included a summary map indicating only locations needed for the task, and the time needed to reach those locations. There were two differences between the temporal tasks. The first was the time frame within which the actions had to be sequenced: the first task involved sequencing actions within a relatively limited timeframe of seven hours, the other a larger timeframe of a week. The second difference was that the temporal task with the timeframe of seven hours contained a large number of order constraints (i.e. certain elements were contingent on other elements, and therefore had to be sequenced in a specific order), whereas the other temporal task contained only one order constraint. These temporal tasks will be referred to as the temporal-sequencing (part of a day) and temporal-scheduling (a week) tasks.

The number of elements in the tasks was kept somewhat even, with the number of elements in the spatial and spatial-temporal task fourteen, the temporal-sequencing task sixteen, and the temporal-scheduling task eleven. The tasks were ill-structured with respect to their goal states, as participants could decide when the plan was complete, and in the spatial, spatial-temporal, and temporal-scheduling tasks they were told they could do as many of the task elements 'as they would normally manage'.

Measures were collected both on planning processes and on planning outcomes. The method used to investigate participants' planning processes was the collection of verbal 'think aloud' protocols according to instructions in (Ericsson & Simon, 1993).

These protocols were coded for verbalizations concerned with spatial or temporal constraints and sequencing. Coding the verbal protocols allowed for comparison of 'planning profiles' for the four tasks. Planning outcome measures for all tasks were constraint violations and task durations. In addition, spatial efficiency and temporal efficiency were calculated for the spatial and spatial-temporal tasks.

A subsidiary aim of the current study was to investigate whether individual differences in cognitive abilities made a difference to participants' planning processes or planning outcomes on these tasks. To this end, various cognitive measures were collected: Verbal and visual working memory, processing speed, verbal and nonverbal fluency, and measures of shifting, updating and inhibition.

It was thought that verbal working memory could be a factor in remembering task constraints, which could affect task durations and constraint violations. Visuospatial working memory was considered a possible factor in spatial efficiency. Processing speed was measured for its possible relationship to task durations. Verbal and nonverbal fluency were expected to be related to total participant-generated constraints and strategy use, respectively. Executive function is now commonly considered a fractionable construct. Miyake and colleagues (2000) concluded that it is best modeled as fractionable into three factors: shifting, updating and inhibition. All three of these factors were measured, and were expected to show some relationship to the 'planning profiles', with the tasks that contained more temporal constraints, expected to relate more strongly to shifting and updating than the tasks with spatial constraints.

Method

Participants

46 participants were recruited from the undergraduate student population via the Rutgers University psychology department subject pool. Participants were given research participation credit or gift certificates for taking part in the study. Data were obtained on 24 males and 22 females. Data were partially lost for one male participant due to a technical failure, but wherever possible his data were included.

Procedure

After completing the informed consent forms, participants were asked if they considered themselves right- or left-handed and if they normally used the non-dominant hand for any actions. Participants then completed four planning tasks. The order of these planning tasks was counterbalanced to control for order and practice effects. Brief (three minute) breaks were offered after the second and fourth planning tasks. A cognitive abilities test battery consisting of ten tests was administered in identical order for all participants after the planning tasks.

 Planning tasks

Prior to the planning tasks the participants were given the instructions for 'thinking aloud' from Ericsson and Simon (1993) (see Appendix 1) which are aimed at eliciting a second level verbalization and which include a practice task. After this practice, participants were given the planning tasks in counterbalanced order. The instructions for the four planning tasks were given to the participants to read out loud, and they were told to 'think out loud while reading the instructions'. This allowed for the capture of any prioritizations, conclusions, evaluations etc. during the reading of the task

instructions. The participants' verbalizations during the planning tasks were recorded via a lapel microphone (Lavalier microphone, Audio-Technica ATR-35S) which was hooked up to a digital recorder (SONY, DCR-TRV30). The participants were also videotaped during the tasks as a backup measure (JVC Compact VHS Camcorder Model# GR-SXM520U).

(a) Errand-running task (spatial task)

The errand-running task was based on a task developed by Hayes-Roth and Hayes-Roth (1979). Participants were presented with a map, task instructions, and blank paper. The map (76 x 102 cm) was mounted on foam board and depicted a town (see Figure 3). The task instructions (see Appendix 2), directed participants to take their time to see where the different stores were located in the town where they would be running their errands. They were given a starting location and time, as well as the time to be at a (different) ending location, and told that they could plan the rest of the day as they liked. In addition they were given a list with ten other errands, and participants were told to get as many of these errands done as they would normally. They also had to include ("if possible") a movie at one of the two movie theaters in the town (show times were given). Participants were also presented with blank sheets of paper on which they were asked to write down their plan. Other than the beginning and ending time, and the movie times, no times were mentioned in this planning task.

As the errands in the task could only be carried out in specific locations this task carried 11 spatial constraints (although there was a choice of two restaurants, two grocery stores, two movie theaters, and three book stores at which the corresponding errands could be done). All errands carried implicit duration constraints, and the movie times also

posed a time constraint. There were no explicit order constraints, although the buying of fresh vegetables is better done late in the errand running day, and constituted an implicit order constraint. The buying of medicine for their dog could be construed as a priority constraint. The task did not contain any resource or person constraints. The basis for an efficient plan on this task is primarily spatial, and secondarily temporal.

(b) Amusement park planning task (spatial and temporal)

The amusement park planning task was designed for this study. Participants were presented with the task instructions to read out loud, a map of a (fictitious) amusement park, a legend giving the durations of the various attractions in the park and the times governing the park train, and blank paper. The map (see Figure 5) had the same dimensions as the town map in the errand running task. In the task instructions (see Appendix 3) the participants were told that they had been dropped off at the amusement park at 11 in the morning, that they were to meet a friend at the East entrance to the park at 2 pm, and that the friend would be babysitting a 9-year-old child, and that they would all leave the park at 5:30 pm. In addition they were given a list with ten activities in the park which one or more of the people in the plan desired to do, and participants were told to get as many of these activities done as they would normally. Participants were asked to plan the day, and write their plan down on the blank sheets of paper provided.

There were two important differences between this task and the errand-running task, even though they were both tasks involving the planning of activities in various locations, and therefore both contained many spatial constraints. The first difference is that in the amusement park the time period which had to be planned was essentially split between the time interval when there was one person to plan for, and the time interval

during which there were three people to plan for. This constrains the times that the

activities can be carried out, as well as imposing another absolute time/location

constraint. The second difference is that in the second time interval, activities had to be

planned for three people, leading to a number of person constraints. Six of the activities

could only be carried out in one location, three of the activities (lunch, ice cream and

playing in water) had as many as 8 possible locations. All activities again carried duration

constraints, which the participants could look up, as the durations were listed in the

legend. An efficient plan for this task had to take the person constraints into account and

be both spatially and temporally efficient. Other than the time interval constraint, there

were no order, priority, or resource constraints.

(c) Cocktail party planning task (temporal-sequencing)

The cocktail planning task was adapted from MacLeod's (2001) task. Participants

were given a small (21.5 x 28 cm) map with walking and driving distances (see Figure 6),

a list of 14 errands that needed to be accomplished between 11:30 am and 7:00 pm by

two friends (see appendix 4), and blank paper. This task involved dividing the errands

over the two friends, and constructing optimal sequences for each of them. One of the

characters in the task does not drive, which poses a person constraint for the five errands

that require driving. The resource constraints in the task (car, money, alcohol) can all be

alleviated, and therefore need to be translated into order constraints. If that is done, there

are ten order constraints in the task: the car has to be fetched before four of the errands

can be performed; money has to be obtained for two of the errands; two errands need to

be preceded by a phone call; the alcohol has to be bought before the cocktails are made;

and the living room has to be vacuumed before the plates are put out. This number of

order constraints means that contingent relationships between task components are the basis for an efficient plan, after which all the duration constraints have to be taken into account for the final plan. Spatial constraints in this task have a very small role, as distances are indicated in terms of durations to cover those distances, and there is no real possibility of spatial efficiency. The cocktail party planning task then, has person constraints, resource constraints which have to be translated into order constraints, and partly as a result of this, many order constraints which have to be reconciled with explicit duration constraints. It contains almost no spatial constraints and no priority constraints.

(d) Spring break planning task (temporal)

In the Spring break planning task participants were presented with a large (64 x 76 cm) grid with seven columns for the Monday through Sunday of a hypothetical spring break, a number of activities or tasks that they had to accomplish or could accomplish during the week, and a blank grid on which to copy their final plan. There was one resource constraint (money), which could be alleviated by working, and which implicitly affected three activities. The resource constraint therefore had to be translated into an order constraint. There were two priority constraints, a 10-page research paper due the morning after spring break, and a promise to grandmother to clean and organize her garage. There was also an explicit time point constraint in that they had a 9 am appointment for a root canal on the Thursday. Participants were allowed to schedule anything additional that they would like to do during their break.

This task was the only one to span a week, rather than six to seven hours of a day, and although there were implicit duration constraints, these could easily be satisfied. There was one resource, and therefore order constraint, two priority constraints and one

time point constraint. There were no spatial constraints or person constraints. This was the most ill-structured of all the planning tasks in that there were only 20 constraints to be dealt with, only one of them explicit, and there is little basis for saying that a plan is efficient. Allotting sufficient time for the 10-page research paper, somewhat distributed over the week, following through on the promise to grandmother, and planning to go to the dentist are necessary, and arranging to make money, or forfeiting the money-requiring activities seem like minimal requirements. A good plan, in this case is any plan that satisfies the few constraints that there were.

Cognitive abilities test battery

(a) Working memory – three tests

Tests leading to measures of verbal, visuospatial sequential memory and visual memory were administered.

As a measure of verbal memory, the digit span forward from the WAIS-III was administered according to the instructions in the WAIS-III manual. This was the first test in the cognitive battery for all participants. In this test the experimenter read out an increasingly longer series of digits at a speed of one per second, which the participant was then supposed to repeat from memory. The items were presented in eight sets of two items, each of the eight sets comprising items of equal number of digits. The discontinue rule for this test was missing both items in an item set. A high score of 16 was possible.

As a measure of visuospatial sequential memory the Corsi block tapping test was administered. It was the fifth test of the cognitive battery for all participants. The Corsi block tapping test was administered with the help of an apparatus consisting of a base (22 cm x 28.5 cm) to which nine blocks were attached in an uneven configuration. The

blocks were numbered on the experimenter's side, which allowed the experimenter to tap

the blocks in a set order, at the rate of about one per second (see Figure 7, for an example

of an item set). There were four item sets, each with three items, consisting of sets of

four, five, six, seven, eight, and two with nine blocks. The item sets were derived from

Busch, Farrell, Lisdahl-Medina, and Krikorian (2005). The total possible score was 16,

and the discontinue rule was three consecutive misses.

As a measure of visual memory a visual patterns test was administered as the

eighth test in the cognitive battery. This test consisted of 16 matrices of increasing size

constructed in line with the description in Della Sala, Gray, Baddeley, Allamano, and

Wilson (1999). The participants were given two pages with empty matrices of sizes

corresponding to the stimuli (see Figure 8 for example of key for coding this test). The

patterns were put onto Powerpoint™ slides, and each presented to the participant for

three seconds (with the timing function in Powerpoint™). The screen then went blank

and the participants were asked to put crosses in the cells of the matrix corresponding to

the black cells on the stimulus. When the participant had finished putting crosses in the

matrix, the experimenter would move to the next pattern presentation in Powerpoint™,

until all 16 patterns had been presented.

(b) Processing speed – two tests

The two processing speed paper and pencil tests from the WAIS-III were

administered according to the instructions in the WAIS-III manual, but for a period of 60

seconds rather than the 120 seconds stipulated for the WAIS-III. In the digit symbol

coding test, which was administered second in the cognitive battery, the participant was

presented with a sheet at the top of which a key was given in the form of the numbers one

to nine, each paired with a symbol. The test boxes each contained a number with an empty box below. After completing seven sample boxes, the time was started and the participant was asked to draw the symbols corresponding to the numbers given as fast as s/he could.

In the symbol search test, which was administered sixth in the cognitive battery, the participant was presented with several sheets containing rows of test items and a sheet with three sample test items. Each row of test items had two symbols on the left, an array of five symbols on the right and Yes and No checkboxes on the far right. The participant had to decide if either of the two symbols on the left was present in the array, and mark the corresponding box. After the three practice items were completed successfully the participants again completed as many test items as possible in the span of 60 seconds.

(c) Fluency – two tests

Two measures of fluency were administered, a measure of semantic fluency and a measure of nonverbal fluency.

As a measure of semantic fluency, participants were asked to generate as many animals as they could within 45 seconds; they were then asked to generate as many things to do at the beach as they could within 45 seconds minute. Participants' valid responses were counted by the experimenter by crossing off numbers on a record sheet as each response was given, and as a backup measure participants' responses were also recorded via the digital audio recorder. The semantic fluency test was administered as the third test in the cognitive battery.

As a measure of nonverbal fluency, participants were asked to complete a figural fluency test. In this test, which was presented as the tenth test in the cognitive battery,

participants were presented with a sheet of paper with six columns of five-dot figures. The five-dot figures (which were similar to the five-face of a die) served as the basis for designs. Participants were asked to make as many different designs as possible in the span of 60 seconds, by drawing straight lines between any of the dots in the five-dot figure.

(d) Executive measures- three tests

Three tests were administered to get measures of executive functions. According to the analysis by Miyake et al. (2000) the executive can be fractionated into shifting, updating and inhibition.

The 'plus-minus' task was administered to obtain a measure of shifting, as the ninth test in the cognitive battery. In this test, participants were first presented with a sheet that had a column of 30 two-digit, randomly generated, non-repeating numbers, and told to add three to each of the numbers as quickly as they could, while the experimenter timed how long this took with a stopwatch. The participants were then given another sheet with a similar column of numbers, and told to subtract three from each of the numbers, again as fast as they could, while being timed. The last sheet also had a column of numbers, and participants were told to add three to the first number, subtract three from the second number, and so on, until the end of the column, again as fast as possible, while being timed. The difference between the mean of the first two times subtracted from the time to complete the third column of numbers, constituted the cost of shifting.

The letter memory test was used as a measure of updating and administered as the seventh test of the cognitive battery. The letter test was also presented via Powerpoint™. This test consisted of 12 items. Each item consisted of a string of letters of one of four

lengths (five, seven, nine, or eleven), which were given in counterbalanced order. Each letter was presented for three seconds by means of the Powerpoint™ timing function. Participants were asked to rehearse the last four letters out loud. So, if the letters presented were GHMSETL, participants should have said G…GH…GHM…GHMS…HMSE…MSET…SETL. After each set, experimenters asked the participants if they were ready for the next set before they initiated it. The lengths of the sets were counterbalanced so that participants would update their memory to the last four letters.

The third executive function test was a standard Stroop test, which was administered as the fourth test in the cognitive battery, to yield a measure of inhibition. This test consisted of three parts: first, participants reading as many color words printed in black ink as they could in 45 seconds; second, naming as many colors of rows of X's printed in various colors, as they could in 45 seconds, and last, naming as many colors in which non-matching color names had been printed, as fast as they could in 45 seconds. The cost of inhibiting the reading of the color-word, and naming the color of the ink it was printed in instead was calculated by subtracting from the number of (correct) responses to the third part, the mean of the responses to the first and second part of the test.

Coding and scoring

Planning tasks

The recordings of the planning task verbal protocols were transcribed from the digital recordings. The transcripts were then checked by a person other than the transcriber, and segmented. In principle each segment corresponded to a statement,

formulated in a sentence or clause. However, because spontaneous speech does not proceed in full sentences, in practice statements were expressed in phrases or words (Ericsson & Simon, 1993). It was relatively easy to segment the transcripts by means of content and pauses in speech. The segmented transcripts were then formatted so that they could be processed by CLAN software.

a. Space-time-sequence coding

In order to establish whether the participants were conceiving of the planning task and their plan constructions in terms of spatial or temporal frameworks, verbal protocols for all four planning tasks were coded with a coding system that assigned codes to all segments in the protocol. All segments in the protocol were classified as either concerning space, time, sequencing or something other. Within the space and time categories there were various further distinctions, between time points, and duration, and between location and distance. See appendix 6 for the coding scheme. The 180 segmented protocols were coded by three coders, who coded 16%, 63%, and 41% of all protocols. 10% of all transcripts were coded by more than one coder to establish reliability, and correlations of $r > 0.90$ were obtained between each pair of coders.

b. Efficiency – distance

For the two tasks with significant spatial constraints the efficiency of the chosen route for the activities was calculated by comparing the length of the participant's route with the optimal route. As the activities that participants chose to undertake was somewhat open to their choice, an optimal route was devised for each participant's chosen list, and utilized for calculations with Goldin and Hayes-Roth's formula, cited in Gauvain and Rogoff (1989): Route efficiency = 100 − ([total distance − optimal distance]

x 100 / optimal distance). This formula has been used in several studies in which route efficiencies were calculated (Gauvain & Rogoff, 1989; Pea & Hawkins, 1987).

c. Efficiency – time

The efficiency of the route in the two spatial tasks does not take into account whether the time needed to complete the activities according to the chosen route is temporally feasible. In order to calculate the temporal efficiency of the chosen route and order of activities, the walking distances were translated into standard times (1 minute/2.5 cm on the maps), and standard times for activities were added to the walking times. In the errand running task, the standard times for activities were obtained by averaging duration estimates for those activities from ten individuals who did not participate in the planning study. In the amusement park task, most standard times were stipulated, and for the other activities, the participants' duration choices were used. The calculated time for the participants' route and activities was then compared to the time available for the task, again using the formula from Goldin and Hayes-Roth, but substituting calculated time and available time for route distances.

d. Constraint violations

All four planning tasks contained constraints of various kinds: location constraints, time point constraints, time interval constraints, order constraints, person constraints, duration constraints and priority constraints. For all four tasks the number of constraint violations was scored. As the four tasks had differing numbers of constraints, proportions of constraint violations were calculated. The constraints were either explicitly stated in the planning task presentation, or had to be inferred by the participants.

e. Duration of planning

The durations of participants' planning for each of the four tasks was noted from the digital recording of their verbal protocol.

Cognitive abilities test battery

Participants' score for the digit span test (verbal memory) was the total number of correct items, with a maximum of 16. Participants' score for the Corsi block-tapping test (visuospatial memory) was the total number of correct items, with a maximum of 16. Participants' score on the visual pattern test (visuospatial memory) was computed by adding the scores for each item. For each of the 16 items, the cells that were marked as having been black on the stimulus were inspected. The total number of incorrectly marked cells was subtracted from the total number of cells, for a cell score per grid. A maximum score of 124 was possible. Participants' scores for semantic fluency were the total number of (unrepeated) items generated during the semantic fluency test. Participants' score for nonverbal fluency was the total number of (unique) designs generated during the design fluency test. Participants' processing speed was taken as the total correct items in both processing speed tests. The processing speed index could not be calculated according to the WAIS manual because, due to time constraints, participants performed the processing speeds tests for only one minute, rather than the two minutes stipulated in the WAIS. For each participant an inhibition cost score was calculated. The mean number of items was calculated on the parts of the test where color names were read and colors of ink were named. From this number was subtracted the number of items for which the color of the ink was named in cases where it conflicted with the color name. A lower inhibition cost score indicates a higher inhibition ability. For each participant a shifting cost score was calculated. The mean time was calculated

for the parts of the test where participants had to add to a column of numbers and subtract from a column of numbers. From this time was subtracted the time taken to alternately add to and subtract from the same number of items. A lower score for shifting cost indicates a higher ability to shift between tasks. For updating, the score was simply the total number of correct items.

Results

For ease of reference the data are conceived of as three sets: the planning process data, the planning outcome data, and the cognitive abilities data.

Preliminary analyses

The planning process and planning outcome data were checked for normality of distribution. Several measures were not normally distributed. As these data were to be analyzed with repeated-measures analyses of variance and the F-test is relatively robust against violations of normality with equal sample sizes greater than 12 (Tan, 1982 cited in Keppel & Wickens, 2004, p. 145) it was decided to retain the data, and note violations of normality where they occur.

Independent-samples t-tests were conducted on all data in order to check for effects of handedness or gender, as both of these characteristics are possibly related to spatial abilities. For handedness it was found that right-handers frame a significantly larger percentage of total planning talk in terms of spatial language in the spatial-temporal task than left-handers (t (43) = 2.34, p = 0.024). Given the small size of the effect (r^2 = 11%), and the fact that this was the only effect of handedness found, all data were collapsed over handedness thereafter. For gender it was found that the males in our sample were significantly better than the females in updating. As homogeneity of variance between the groups was violated, a Mann-Whitney U test was used (Z = -2.24, p = 0.025). Again, given the size of the effect, and the fact that this was the only significant effect of gender, all data were collapsed over gender thereafter.

Differences in planning process measures between tasks

The first set of analyses were conducted on the planning process measures (the proportion of planning that was spent solving the planning task in terms of time, space or sequencing, as well as the total number of plan segments) to see if they differed across the four tasks. The planning process measures were designed to pick up conceptualizations related to the constraints that varied the most between tasks, and it was therefore expected that these measures would reflect task constraints. Separate one-factor (task) repeated measures analyses of variance were conducted for each of the planning process measures.

Sequencing segments

A one-factor repeated measures analysis of variance on the proportion of planning segments concerned with sequencing showed a significant main effect (F= 4.63, $p < 0.001$), see Figure 9. Paired comparisons found that there was significantly more sequencing talk during the temporal-sequencing task than during the other tasks ($p < 0.01$). There were no significant differences between any of the other tasks. [1] The larger number of sequencing segments in the temporal-sequencing task is thought to reflect the fact that the temporal-sequencing task had many more order constraints than the other tasks.

Space-related segments

A one-factor (task) repeated measures analysis of variance on the proportion of segments of space-related talk across tasks, showed a significant main effect ($F = 257.95$, $p < 0.001$), see Figure 10. The sphericity assumption was violated so the Huyn-Feldt

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[1] Although the sequencing data on the temporal-sequencing task were not normally distributed, the *F*-task is considered to be robust against normality violations (Tan, 1982 cited in Keppel & Wickens, 2004)

corrected significance levels were used. Pairwise comparisons showed that each task was significantly different from the others ($p < 0.001$). The proportion of segments with space-related talk tracks the proportion of explicit spatial constraints contained in the tasks.[2]

Time-related segments

A one-factor (task) repeated measures analysis of variance on the proportion of segments of time-related talk (i.e. talk about time points and duration), showed a significant main effect ($F = 66.86$, $p < 0.001$), see Figure 11. Pairwise comparisons showed that each task was significantly different from the others ($p < 0.001$). The proportion of segments with time-related talk appear to be related to the proportion of explicit time constraints contained in the tasks. [3]

Total number of segments

A one-factor repeated measures analysis of variance on the total number of segments, showed a significant main effect ($F = 19.45$, $p < 0.001$), see Figure 12. The sphericity assumption was violated so the Huyn-Feldt corrected significance levels were used. Pairwise comparisons showed that each task was significantly different from the others ($p < 0.001$ except for the difference between the spatial and the temporal-scheduling task, which was $p < 0.05$). The mean number of segments for the tasks appears to be related to the total number of constraints contained in the tasks.[4]

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[2] Although the space-related data on the temporal-scheduling task were not normally distributed, the *F*-task is considered to be robust against normality violations (Tan, 1982 cited in Keppel & Wickens, 2004).
[3] Although the time-related segment data on the spatial-temporal task were not normally distributed, the *F*-task is considered to be robust against normality violations ((Tan, 1982 cited in Keppel & Wickens, 2004).
[4] Although the total segment data for the spatial-temporal, temporal-scheduling and temporal-sequencing tasks were not normally distributed, the *F*-task is considered to be robust against normality violations (Tan, 1982 cited in Keppel & Wickens, 2004).

Figure 13 shows all the proportions for time-related, space-related and sequencing segments per task to illustrate the relative importance of these different strategies for the various tasks.

The results for these planning process measures show very clearly that participants' conceptualization of the planning tasks in terms of space or time, their focus on sequencing, and the quantity of verbalizations were related to the proportions of spatial, temporal and order constraints, as well as the total numbers of constraints in the tasks.

Individual differences in planning process measures between tasks

The second set of analyses investigated the extent to which individuals used the same strategies for framing their solution to the planning task over different tasks. By identifying whether any strategies were consistently used across tasks, we learn to what extent these planning processes are 'general' rather than task-specific. Correlations were calculated between planning process measures for the four tasks (see Table 2). It appears that the degree to which participants used sequencing was related between some of the tasks: there was a relationship between sequencing on the spatial task and both the spatial-temporal and the temporal-sequencing task.

The degree to which participants framed their thoughts in terms of space appears completely unrelated between tasks.

The degree to which participants framed their thoughts in terms of time, however, was more consistent across tasks, with a relationship between the total time-related segments between the spatial task and both the spatial-temporal and the temporal-sequencing task, and between the spatial-temporal and the temporal-scheduling task. A

further breakdown of the time-related segments by type of reference to time may be found in Table 3. The degree to which participants referred to points in time was highly related across tasks. Similarly the degree to which participants referred to anchored duration (e.g. between 2 and 4 o'clock, from 12 to 12:15) was very much related between the three tasks that required sequencing activities within the frame of a day (spatial, spatial-temporal, temporal-sequencing), but not with the task that required sequencing within the frame of a week (temporal-scheduling). The degree to which participants referred to absolute duration (e.g. 20 minutes, half an hour) was related between the spatial task and the spatial-temporal task.

The number of total segments was highly related across all tasks.

These results show that to some extent planning processes are 'general', as participants were somewhat consistent in their use of sequencing, and highly consistent in the degree to which they framed their planning in terms of time as well as in their total verbalizations.

Differences in planning outcome measures between tasks

The third set of analyses was conducted on the planning outcome measures (the proportion constraint violations and total plan durations for all tasks, the spatial and temporal efficiency for the spatial and spatial-temporal tasks) to see if they differed across the four tasks. It was expected that the planning outcome measures also would be related to the constraints contained in the tasks. Separate one-factor (task) repeated measures analyses of variance were conducted for each of the planning outcome measures.

Spatial efficiency

The spatial efficiency measures for both the spatial and the spatial-temporal task were not normally distributed due to ceiling effects (the maximum spatial efficiency is 100). A Wilcoxon signed ranks test was conducted, and no significant difference was found between the two tasks on spatial efficiency, although the mean spatial efficiency in the spatial task was larger than the mean for the spatial-temporal task (see Figure 14). The direction of this difference is the same as for the spatial constraints in the task.

Temporal efficiency

The data for temporal efficiency in the spatial task were bimodal (see Figure 15), therefore a groupwise comparison of temporal efficiency between the spatial and the spatial-temporal tasks was conducted with a Wilcoxon signed ranks test. This showed a slightly significant effect ($z = -2.07$, $p < 0.05$), with temporal efficiency being higher in the spatial-temporal task than in the spatial task (see Figure 16). The direction of the difference is consistent with the direction of the proportion of explicit time constraints in the tasks.

Constraint violations

A one-factor repeated measures analysis of variance on the proportion of constraint violations between tasks showed a significant main effect ($F = 20.63$, $p < 0.001$), see Figure 17. The sphericity assumption was violated so the Huyn-Feldt corrected significance levels were used. Pairwise comparisons showed that the spatial and spatial-temporal tasks were not significantly different from each other, but both were significantly different from the temporal-sequencing and the temporal-scheduling task. In addition the temporal-sequencing and the temporal-scheduling task were also

significantly different ($p < 0.01$). The mean proportion of constraint violations for each task appears to be related to the proportion of implicit constraints in the tasks.

Task duration

A one-factor repeated measures analysis of variance on the total duration per task, showed a significant main effect ($F = 24.57$, $p < 0.001$), see Figure 18. Pairwise comparisons showed that there was no difference between the spatial task and the temporal-scheduling task, and the difference between the spatial-temporal and temporal sequencing tasks was only marginally significant ($p < 0.05$). The other four differences between tasks were all significant at $p < 0.001$. The mean task durations appear to be somewhat related to the total number of constraints contained in the tasks.[5]

As with the planning processes, it appears that the differences in planning outcomes across tasks can be related to the differences in constraints contained in those tasks.

Individual differences in planning outcome measures between tasks

A fourth set of analyses was conducted to investigate the extent to which individuals had consistent planning outcomes over different tasks. Correlations were calculated between planning outcome measures for the four tasks. For spatial and temporal efficiency, nonparametric tests were used, due to the type of normality violations in the data (bimodality and ceiling effects). The Spearman correlations for spatial and temporal efficiency between the spatial and the spatial-temporal task were not significant. The correlations for constraint violations and task durations are given in Table 4. The degree to which participants violate constraints across tasks does not appear

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[5] Data for the spatial-temporal, temporal-sequencing and temporal-scheduling tasks were not normally distributed.

to be consistent across tasks, although the correlation between constraint violations in the two temporal tasks is marginally significant. On the other hand, participants appear to be quite consistent in the relative length of their task durations.

On the whole participants' outcome measures showed very little relationship between tasks. It appears that participants' consistency in the use of particular planning strategies does not translate into consistency among planning outcomes.

Relationships between planning process and planning outcome measures

A fifth set of analyses was conducted in order to evaluate the relationship between the planning processes employed by the participants and the planning outcomes achieved. It was expected that a concern with space would result in greater spatial efficiency, and concern with time in greater temporal efficiency. Correlations were calculated between these measures by task (see Table 5).

In the spatial task, framing the planning in terms of space appears to relate to greater spatial efficiency. This is not the case in the spatial-temporal task. In that task, a greater degree of sequencing appears to be related with a lesser degree of spatial efficiency. In the case of both the spatial and the spatial-temporal tasks a greater degree of sequencing appeared to be related to shorter task durations. In the spatial task, framing the planning in terms of time appeared related to longer task durations. In all tasks the total number of segments was related to task duration.

Differences in planning process and outcome measures in relation to cognitive abilities

The last set of analyses was conducted in order to investigate if differences in cognitive abilities were systematically related to differences in planning process or planning outcome measures. The continuous scores for cognitive abilities were converted

to categorical scores. For each cognitive ability, participants were assigned to one of three levels. This resulted in levels with approximately equal numbers of participants, as participants with tied scores were placed in the same level. Separate 3 (cognitive ability level) x 4 (task) mixed-model repeated measures analyses of variance were conducted for all cognitive abilities and all planning and process measures, with cognitive ability level as between-subjects measure and task as within-subjects measure. Given that the large number of analyses entailed a greater risk of type I error, a more conservative criterion for significance ($\alpha = 0.01$) was used. Results for the analyses of the planning process measures are presented in Table 6 and those for the analyses of planning outcome measures in Table 7.

There were very few effects of level of cognitive ability on planning process measures. Amount of sequencing in the spatial and spatial-temporal task varied with level of Corsi visuo-spatial memory (see Figure 19).

There also appears to be an effect of category level of nonverbal fluency on the degree of sequencing across all the tasks, with those in the highest category of nonverbal fluency engaging in significantly more sequencing than those in the lowest level of nonverbal fluency (see Figure 20)

There was only one effect of cognitive abilities on planning outcome measures. The middle level of verbal working memory appears to have longer task durations than the lowest and highest level of verbal working memory (see Figure 21).

Discussion

One of the main goals of this study was to investigate whether the parameters in planning tasks determine performance on these tasks. First, the results of the present study show that the conceptualizations during the planning task are clearly related to the constraints contained in that task. The findings also show that individuals are consistent in their conceptualization strategies across tasks, which may be the reason that planning outcomes are less strongly related to the constraints in the tasks than planning processes are. The findings also show that there is little consistency in planning outcomes across tasks in individuals. Finally, this study found very few effects of cognitive abilities on either planning processes or planning outcomes. Each of these ideas will be discussed more fully in this section.

Planning processes depend on task constraints

This study examined the degree to which participants focused on how to sequence their actions across tasks that included varying numbers of order constraints. The findings show that participants engage in a lot more sequencing during the task that included the highest number of order constraints as compared to other tasks that included few to no order constraints, but the amount of sequencing was similar across those other tasks. Ten of the fourteen elements of the temporal-sequencing task were either a prerequisite for another element, or required the completion of another element as a prerequisite. The spatial, spatial-temporal and temporal-scheduling tasks had few order constraints.

The results also show that the degree to which participants phrased their planning in terms of space was strongly related to the proportion of explicit space constraints contained in the tasks. It was interesting in this regard that participants used more space-

related verbalizations during the temporal-sequencing task than one would expect given that spatial efficiency was not an issue in that task. However, this can probably be explained by the fact that seven of the fourteen elements of the task were not at the main location.

The degree to which planners verbalized their solutions in time-related terms was somewhat related to the proportion of explicit time constraints in the various tasks. This was not as straightforward a relation as that between the level of space-related talk and the explicit space constraints. All the tasks required reference to time, given that all the tasks required sequencing actions within a restricted timeframe. The proportion of explicit time constraints is the same in the spatial-temporal and the temporal-sequencing tasks, but participants framed a lot more of their planning in terms of time during the latter than the former. This could be due to the fact that the basis for an efficient plan in this task is sequencing the elements according to the order constraints, and fitting the resulting order into the limited time frame. This means that even though the proportion of explicit time constraints is the same as in the spatial-temporal task, the concern with time looms larger. Similarly for the temporal-scheduling task, with has but one explicit constraint, which is a time constraint. This leads to a somewhat misleading figure for the proportion of explicit time constraints. However, the only concern in this task is deciding how much time (duration) to allocate to various activities and when in the frame of the week to perform the activities, resulting in a very high proportion of time-related verbalizations.

The total amount of verbalizing that participants engage in during their planning of the different tasks is related to the total number of constraints in the tasks. The

difference in the amount of planning talk between the spatial-temporal and the temporal-sequencing tasks, which have almost equal number of constraints, but much more talk during the former than the latter, could possibly be explained by the fact that the constraints in the spatial-temporal task are divided over spatial, temporal and other (mostly person) constraints, rather than temporal and order constraints in the temporal-sequencing task. An interesting theory in connection to the switching between spatial constraints and the map on the one hand, and temporal and person constraints on the other hand, is the gateway hypothesis recently proposed by Burgess, Dumontheil and Gilbert (2007). They suggest, based on functional imaging and lesion studies, that the function of the prefrontal rostral cortex is to switch attention between external and internal stimuli. Patients with lesions to the prefrontal rostral cortex have great problems with both the Multiple Errands Task and the Six Elements Task (planning tasks discussed earlier), problems that are thought to be due to difficulties in switching between external and internal stimuli. The gateway hypothesis proposes a function for a specified brain structure, and does not lead to specific predictions for the tasks used in the current study, as all require some switching between external and internal stimuli. It does however remind us that switching is an important feature of planning tasks, and allows speculation that tasks that require more switching could be more difficult, and therefore require more verbalizations to solve.

Individuals use some of the same strategies for planning processes across different tasks

The results show that individuals are extremely consistent across tasks in two aspects of their planning processes: the degree to which they refer to points in time ('on Wednesday', 'at 3 o'clock', 'now') during their planning, and the amount of verbalizing

relative to other individuals in the study. The degree to which individuals sequence is consistent across some tasks, but the degree to which participants refer to space during their planning is not consistent across tasks at all.

All four tasks in this study require the sequencing of elements within a limited time frame. It is therefore perhaps not surprising that the most consistent strategy is that of referring to time-points. It is very interesting in this regard that the strategy of framing some time-references in terms of anchored duration ('between 5 and 7', 'from 12 to 12:30') is consistent across the three tasks that require sequencing of elements within a period of six or seven hours in a day, and completely unrelated to the task that requires scheduling activities over a week. This suggests that the timeframe of the task influences the way that participants think about time in the task. Absolute duration ('an hour', 'ten minutes'), is a time-reference strategy that is strongly related between the spatial and spatial-temporal task, somewhat less strongly between the spatial and the temporal-sequencing task, and not significantly related between the other tasks. Why use of absolute durations is not consistent between the spatial-temporal and the temporal sequencing task is a good question.

Given the consistency of time-reference strategies across tasks, the utter lack of consistency of space-reference strategies stands out. Why do participants not consistently refer to space, be it location, absolute or relative, or distance, even between the two tasks that were designed with spatial constraints? It is possible that this is an issue of verbalizing. The data were gathered from verbal protocols, but verbalizing locations or judgment of spatial relations or routes may be more difficult for participants than verbalizing times or temporal relations. It is possible that looking times coded from the

videos of participants' looking to the maps (or the large time-schedule used in the temporal-scheduling task), and from location to location on these visual stimuli, would give a better measure of concern with spatial aspects of the task than the parsing of verbal protocols allows. It should be pointed out in this regard that the planfulness measure on Mayhew (2004) and Gauvain and Rogoff (1989) involved coding children's scanning behavior of a grocery store in advance of making shoppers move. The looking time measure suggested for participants in the current study would be quite similar to the scanning, a measure which was significantly related to distance efficiency in both studies.

The use of sequencing is consistent between the spatial and spatial temporal task, as well as between the spatial and the temporal-sequencing task. It is not consistent between the other four pairs of tasks. Given that the temporal-scheduling task does not really call for sequencing, it is not entirely surprising that sequencing in that task is not related to sequencing in any of the other tasks. It is the length of the timeframe that makes this task less constrained, which results in a reduced need for sequencing, and in that task it may just indicate an incidental strategy. It is however surprising that sequencing is not consistent between the spatial-temporal and the temporal-sequencing task.

The amount that individual participants talk while solving the planning tasks relative to other participants is also highly consistent across tasks. Those who talk a lot during one task very likely talk a lot during the other tasks, and those who solve one task in fewer verbalizations do the same with the other tasks. Whether this consistency is due to impulsivity, decisiveness, caution, trouble with the tasks or different factor(s) for each participant is impossible to say.

The consistency of some of the planning process measures across tasks suggests that to some extent these processes are 'general'. This is an interesting finding considering the relative lack of consistency that was found in earlier studies. It is possible that this consistency was found here as a result of comparing the same measures across tasks.

Planning outcomes are moderately related to task constraints

The results show that the planning outcome measures are somewhat related to the task constraints, explicit or implicit. The degree to which the chosen routes in the spatial and the spatial-temporal tasks were spatially efficient was not significantly different between the two tasks, but the mean spatial efficiency in the spatial task, which contained the higher proportion of explicit spatial constraints, was higher than in the spatial-temporal task. It is thought that the salience of the spatial constraints in the spatial task (82% of the explicit constraints in this task are spatial constraints) leads participants to pay more attention to the spatial basis of an efficient plan than in the spatial-temporal task (only 37% of the explicit constraints are spatial).

The degree to which the participants' plans were temporally efficient was significantly different between the two tasks in which it was possible to compute it. Participants constructed more temporally efficient plans in the spatial-temporal task, in which 53% of the explicit constraints were temporal, than in the spatial task, in which only 18% of the explicit constraints were temporal. Again, it is suggested that it is the salience of the temporal constraints that draws the attention to temporal efficiency, and results in the difference between the spatial and the spatial-temporal task.

A very important part of planning is taking into account all the constraints that inhere in a planning task, and constraint violations are therefore an interesting measure. Results showed that the proportion of constraint violations was not significantly different between the spatial and spatial-temporal tasks, but significantly different between all other pairs of tasks. It appears that participants are more prone to violating implicit constraints than explicit constraints, as differences in constraint violations closely track the differences in the proportion of implicit constraints. The temporal-scheduling task, which had the fewest total constraints, also had the most implicit constraints (all but one constraint was implicit), and by far the highest proportion of constraint violations. The temporal-sequencing task had almost the highest number of total constraints, but only 37% of these were implicit, resulting in the lowest proportion of constraint violations.

The total durations for the planning tasks, which very closely reflect participants' total verbalizations, vary with the total constraints in the task. There is no significant difference between the spatial (31 constraints) and temporal-sequencing (20 constraints) tasks. The difference between the spatial-temporal (52 constraints) and the temporal-sequencing (51 constraints) is barely significant. That the time that participants take on a task is related to the difficulty of the task, as measured by the number of constraints in the task, is hardly surprising.

Individuals' planning outcome measures differ across tasks

Planning outcomes measures showed very little relationship between tasks. Participants who produced a spatially efficient plan in one task did not necessarily do so on the other task where spatial efficiency could be calculated. Temporal efficiency was not related across these tasks either, and there was only a marginal consistency in

constraint violations between the temporal-sequencing and the temporal-scheduling tasks. The consistency in task durations is thought to be due to individual factors.

The lack of relationship between planning outcome measures across tasks is the same finding of the studies that suggested that planning was not a general skill. The tasks in this study were all similar in ecological validity of cover stories, stages of planning, scoring of tasks, laboratory environment, stimulus presentation, and the difference in planning outcomes cannot therefore be ascribed to these factors.

What was different between tasks was the difference in the numbers, types and level of explicitness of the constraints in the tasks. These differences in the task constraints do seem to relate to groupwise differences in outcome measures among our participants. Why then is it that our participants who are good at coming up with a spatially or temporally efficient plan in one task, are not good at concocting such a plan in another task? Perhaps the different constraints among the tasks affect participants to different degrees. It is possible that their strategies for framing the tasks, which are very consistent across tasks insofar as temporal framing is concerned for example, are more or less successful, depending on the constraints in the task at hand. This might be evident in the relationships between the planning process measures and the outcome measures.

Relationships planning process measures and planning outcome measures

This study investigated four different planning process measures, two of which had to do with the framing of the plan in terms of space-related or time-related talk, one of which concerned sequencing talk, and one of which concerned the total amount of talking that solving the planning task required. The space- and time-related verbalization was chosen for coding because it was surmised that those who noticed the spatial and

temporal constraints in the tasks would engage in more talk recognizing these constraints and taking them into account. It was further thought that as planning is essentially the sequencing of future actions under constraints, a measure of the amount of sequencing that a participant engages in could also serve as a predictor of planning outcome.

Interestingly it turned out that although groupwise space- and time-related verbalization, and sequencing could be related to the constraints in the tasks, it was only very rarely related to planning outcome measures. It *was* found that a greater number of space-related verbalization is related to greater spatial efficiency in the spatial task. This relationship is as one would expect, however, this relationship does not hold in the spatial-temporal task. There is no relationship between space-related talk in the spatial-temporal task and the spatial efficiency in that task. It is possible that the temporal constraints in the spatial-temporal task draw the attention away. Similarly for time-related talk, although participants are highly consistent across tasks in the degree of time-related talk, this has no relationship whatsoever with their temporal efficiency.

If the amount of talk related to the nature of the constraints in the task does not relate to the efficiency that comes with taking the constraints into account, then what does? It is possible that what really makes the difference in efficiency is the plan construction process, not just noticing the constraints and talking about them, but heeding them. This would call for coding on the plan construction level, if not according to the Hayes-Roths' model, then at least a kind of coding that would recognize for example plan problem representation, recognition of constraints, generation of ideas or strategies, sequencing, evaluation, and monitoring. This type of coding (akin to what was used in

the financial planning study by Goel et al. (1997) was not carried out in this study, and should perhaps be completed in the future.

There is one other relationship between planning process measures and planning outcome measures that is interesting in this regard. It is the finding that a greater degree of sequencing results in shorter task durations (a significant relationship in the spatial and spatial-temporal tasks, and a nonsignificant tendency in the temporal-sequencing task). Remember that participants' sequencing was consistent across these same tasks. This suggests that sequencing, although it does not lead to greater spatial or temporal efficiency, at least leads to shorter planning duration.

Participants' constraint violations were not in any way related to the degree to which they verbalized in terms of space or time or sequencing during planning. This is not surprising, given that proportion of constraint violations were found to be related to the proportion of implicit constraints. If the participant did not recognize an implicit constraint, s/he was more likely to plan in violation of the constraint. Recognizing implicit constraints was not something that our planning process measures were designed to 'catch', and it is therefore not surprising that there is no relation between these measures and constraint violations.

Very few relationships between cognitive abilities and planning process and planning outcome measures

The most surprising finding of this entire study was the lack of relationship between cognitive abilities and planning process and outcome measures. Most of the measures used in the current study are on the level of task operations. It was thought that it would be possible to link cognitive abilities, which are constructs, to the task

operations. We found a number of relationships: higher levels of sequential visuo-spatial working memory, as assessed by the Corsi block tapping task, and higher levels of nonverbal fluency were both found to be related to higher amounts of sequencing across tasks. This echoes the findings of Kliegel et al. (2002), in whose sample nonverbal fluency was also related to planning process measures. In addition we found that those with medium levels of verbal working memory took longer to complete tasks than those with either lower or higher levels of verbal working memory.

There were many other possible effects of memory, both verbal and visuospatial, as well as of processing speed or executive function that did not materialize in our study. It is possible that although reduction in working memory load has the effect of improving performance in children (e.g. Klahr & Robinson, 1981), working memory capacity and processing speed differences no longer have a noticeable impact on performance in young adults. Pea and Hawkins (1987) were also disappointed in finding only weak relationships between digit span and effective planning (as measured by spatial efficiency), and performance on the WISC block test and effective planning.

The lack of relationships between executive functions and our planning measures was also surprising, as planning is often considered to be a clear example of higher-level thinking that engages executive functions. The literature shows that executive functions, measured by similar instruments as used in the current study, are related to school performance in mathematics, science and English (for a review see St. Clair-Thompson and Gathercole, 2006). It is possible that the effect of good executive functions is of a magnitude that is hard to detect in brief tasks as used in the current study, but that slight advantages accrue over time.

On the whole this study has shown that 'quantifying' planning tasks in terms of constraints is a valuable strategy, as it furnishes a common denominator among tasks that are otherwise difficult to compare. All tasks can be assessed on constraint violations if these are adequately specified. The specification of constraints in tasks also allows attention to the extent to which planners talk about constraints, and recognize implicit constraints.

It is essential to remember that one of the most important parts of planning is the recognition of implicit constraints. A desire for experimental control may tempt one to make all constraints explicit, e.g. in the Plan-a-day task the priority of various elements of the task is specified; going to the bank is very important, going to the post office is important etc. This tends towards a well-structured task. However, most people's errand lists do not come pre-assigned with importance levels. It could be very interesting to investigate whether certain types of constraints are more easily recognized when implicit than others. Is it easier to appreciate that fetching medicine for your dog is an important errand (a priority constraint), or that if you are told to go feed the ducks you need to obtain something to feed them and not just go to the pond (a resource constraint)? Does it take a different thinking process to recognize the one than the other?

One of the limitations of the current study is that there is no one measure quantifying a 'good' plan. It is possible to conceive of some measure in which task duration, spatial and temporal efficiency and constraint violations are combined. Again, with task duration and constraint violations measurable across tasks with many different classes of constraints, these may be the more universal ingredients of a plan effectiveness measure.

The most interesting finding to emerge from the current study is that planning processes do appear to be somewhat 'general': participants are quite consistent in some of the strategies they use to deal with the planning tasks. Planning outcomes however, are not consistent across tasks. People who come up with a spatially efficient plan in one task do not necessarily do so in another task, and those who violate lots of constraints in one task, do not necessarily do so in another task. It is therefore inadvisable to generalize the findings on planning outcomes from one task to all planning tasks, even though there appears to be some basis for generalizing findings on planning processes.

Table 1. Relationships between measures on types of planning task

	Tower tasks	Six element task	Errand running tasks	Time tasks
Six element task	n.s. [1,3] TOL effectiveness measure, SET planfulness TOL effectiveness, SET plan effectiveness	--		
Errand running tasks	0.29 $p < 0.01$ [2] TOH effectiveness, grocery store plan effectiveness	0.31 $p < 0.05$ [1] SET planfulness, and PAD effectiveness	--	
Time tasks	n.s. [3] TOL effectiveness, cocktail party task effectiveness	n.s. [3] simplified SET performance, cocktail party task	n.s. [4] grocery store task planfulness, plan effectiveness and school week scheduling task	--
Social planning task	n.s. [2] TOH effectiveness, social planning planfulness and plan effectiveness	Not carried out	n.s. [2] grocery store task planfulness, plan effectiveness social planning planfulness and plan effectiveness	Not carried out

[1] Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2002). Complex prospective memory and executive control of working memory: A process model. *Psychologische Beitrage, 44*(2), 303-318.

[2] Wallner, K. E. (1996). *Executive functioning and its relation to planning skill in seven-year-old children.* Unpublished Dissertation, University of Maryland, College Park.

[3] MacLeod, M. S. (2001). *Cognitive ageing and the role of the frontal lobes in prospective memory and planning.* Unpublished Dissertation, University of Aberdeen, Aberdeen, UK.

[4] Mayhew, E. M. Y. (2004). *Planning in elementary school children: Performance on two tasks.* Unpublished Master's thesis, Rutgers, the State University of New Jersey, New Brunswick.

Table 2

Intercorrelations between tasks for planning process measures

Task	Spatial-temporal	Temporal-sequencing	Temporal-scheduling
Sequencing segments ($n = 45$)			
Spatial	0.59***	0.43**	0.16
Spatial-temporal	-	0.20	0.22
Temporal-sequencing	-	-	0.22
Space-related segments ($n = 45$)			
Spatial	0.24	0.04	0.17
Spatial-temporal	-	0.18	0.08
Temporal-sequencing	-	-	0.03
Time-related segments ($n = 45$)			
Spatial	0.48**	0.41**	0.28
Spatial-temporal	-	0.26	0.43**
Temporal-sequencing	-	-	0.28
Total segments ($n = 45$)			
Spatial	0.63***	0.52***	0.50***
Spatial-temporal	-	0.66***	0.49**
Temporal-sequencing	-	-	0.25

** $p < 0.01$

*** $p < 0.001$

Table 3.

Intercorrelations between tasks for time-reference measures

Task	Spatial-temporal	Temporal-sequencing	Temporal-scheduling
Reference to points in time ($n = 45$)			
Spatial	0.45**	0.47**	0.44**
Spatial-temporal	-	0.53***	0.44**
Temporal-sequencing	-	-	0.34*
Reference to anchored duration ($n = 45$)			
Spatial	0.53***	0.63***	0.04
Spatial-temporal	-	0.45**	0.05
Temporal-sequencing	-	-	0.18
Reference to absolute duration ($n = 45$)			
Spatial	0.52***	0.44**	0.21
Spatial-temporal	-	0.25	0.22
Temporal-sequencing	-	-	0.28

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 4.

Intercorrelations between tasks for constraint violations and task durations

Task	Spatial-temporal	Temporal-sequencing	Temporal-scheduling
Constraint violations ($n = 45$)			
Spatial	0.16	0.04	0.10
Spatial-temporal	-	0.18	0.15
Temporal-sequencing	-	-	0.35*
Task durations ($n = 45$)			
Spatial	0.57***	0.43**	0.44**
Spatial-temporal	-	0.54***	0.34*
Temporal-sequencing	-	-	0.41**

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 5

Intercorrelations between planning process and planning outcome measures

Measure	Sequencing segments	Time-related segments	Space-related segments	Total segments
Spatial task ($n = 45$)				
Temporal efficiency	- 0.18	- 0.19	0.15	- 0.08
Spatial efficiency	- 0.07	- 0.12	0.40**	0.27
Constraint violations	- 0.05	0.09	- 0.10	- 0.07
Task duration	- 0.40**	0.36*	0.15	0.85***
Spatial-temporal task ($n = 45$)				
Temporal efficiency	- 0.25	- 0.13	- 0.00	0.11
Spatial efficiency	- 0.35*	0.25	0.10	0.16
Constraint violations	0.06	0.06	- 0.01	- 0.02
Task duration	- 0.36**	0.01	- 0.12	0.86***
Temporal-sequencing task ($n = 45$)				
Constraint violations	0.22	- 0.05	- 0.13	- 0.21
Task duration	- 0.27	0.22	0.07	0.75***
Temporal-scheduling task ($n = 45$)				
Constraint violations	0.17	0.10	- 0.03	- 0.16
Task duration	- 0.08	- 0.11	0.23	0.84***

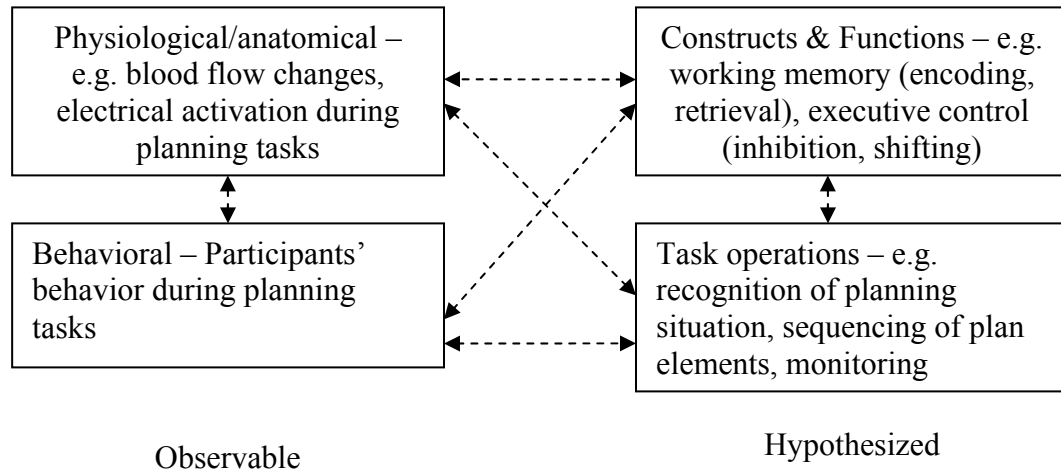* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 6. Differences in planning process measures in relation to cognitive abilities levels

Cognitive Ability	Sequencing segments	Space-related segments	Time-related segments	Total segments
	(n = 45)			
Verbal working memory	n.s.	n.s.	n.s.	n.s.
Verbal fluency	n.s.	n.s.	n.s.	n.s.
Visuo-spatial working Memory – Corsi	$F = 5.16$, $p < 0.01$ level 3 > level 1 spatial & spatial-temporal	n.s.	n.s.	n.s.
Visuo-spatial working Memory – VPT	n.s.	n.s.	n.s.	n.s.
Nonverbal fluency	$F = 5.82$, $p < 0.01$ level 3 > level 1 all tasks	n.s.	n.s.	n.s.
Processing speed	n.s.	n.s.	n.s.	n.s.
Inhibition costs	n.s.	n.s.	n.s	n.s.
Shifting	n.s.	n.s.	n.s.	n.s.
Updating costs	n.s.	n.s.	n.s.	n.s.

Table 7. Differences in planning outcome measures in relation to cognitive abilities levels

Cognitive Ability	Spatial efficiency	Temporal efficiency	Constraint violations	Total duration
		(n = 45)		
Verbal working memory	n.s.	n.s.	n.s.	$F = 7.18, p < 0.01$ level 2 > level 1 & 3
Verbal fluency	n.s.	n.s.	n.s.	n.s.
Visuo-spatial working Memory – Corsi	n.s.	n.s.	n.s.	n.s.
Visuo-spatial working Memory – VPT	n.s.	n.s.	n.s.	n.s.
Nonverbal fluency	n.s.	n.s.	n.s.	n.s.
Processing speed	n.s.	n.s.	n.s.	n.s.
Inhibition costs	n.s.	n.s.	n.s	n.s.
Shifting	n.s.	n.s.	n.s.	n.s.
Updating costs	n.s.	n.s.	n.s.	n.s.

Figure 1. Levels of description and explanation. Dashed arrows indicate that concepts from all levels of description could theoretically be mapped onto those from other levels.
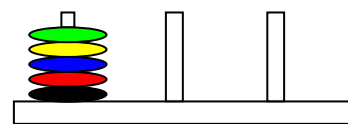

| Physiological/anatomical – e.g. blood flow changes, electrical activation during planning tasks | Constructs & Functions – e.g. working memory (encoding, retrieval), executive control (inhibition, shifting) |
| Behavioral – Participants' behavior during planning tasks | Task operations – e.g. recognition of planning situation, sequencing of plan elements, monitoring |

Observable   Hypothesized

Figure 2. Tower tasks

Tower of Hanoi   Tower of London   5-disk Tower of London

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Figure 3. Small-scale version of map for errand planning (Hayes-Roth & Hayes-Roth, 1979)

Figure 4. Map for errand running task in Burgess et al. (2005)

Figure 10.1 Display given to participants performing the Shopping Plan Test (SPT) (see Box 10.1 for test instructions, and Box 10.2 for an example test performance).

Figure 5. Small-scale version of map for amusement park planning task.

Figure 6. Small scale version of map for cocktail planning task.

Figure 7. Example of item set for Corsi block tapping task – experimenter version

3 – 4 – 8 – 7 – 5   8 – 1 – 5 – 3 – 6   6 – 4 – 5 – 2 – 9

Figure 8. Key for items in the Visual Patterns test.

8

9

10

Figure 9. Proportion of segments concerned with sequencing (+/- SE)

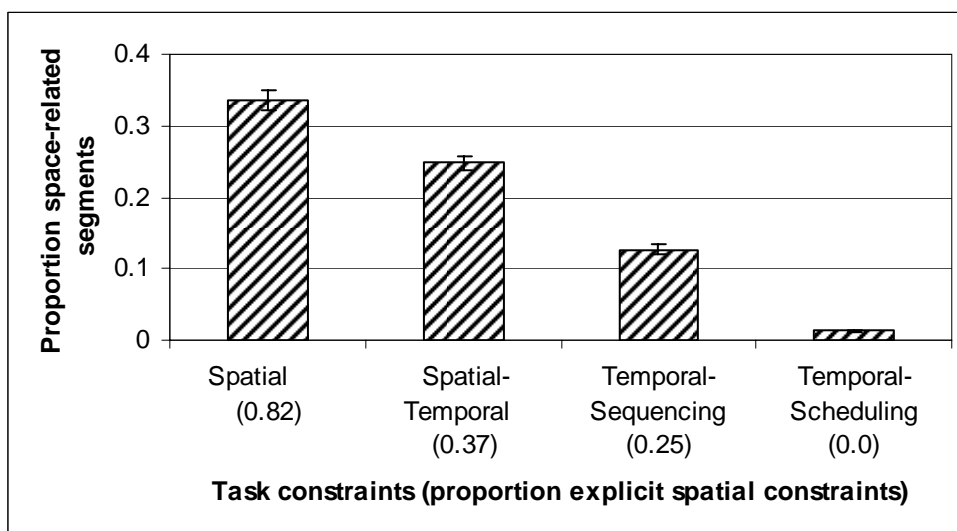*Figure 10.* Proportion of segments concerned with space-related talk (+/- SE)

Figure 11. Proportion of segments concerned with time-related talk (+/- SE)
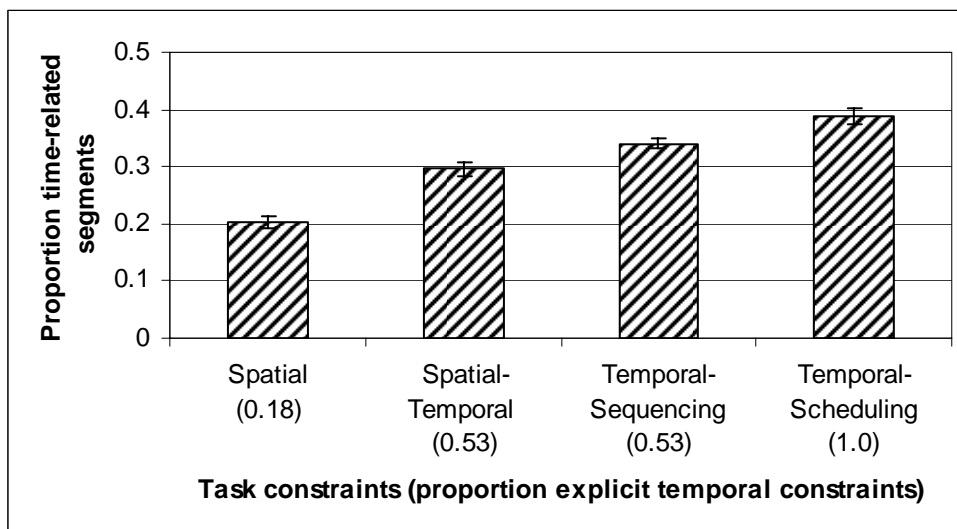
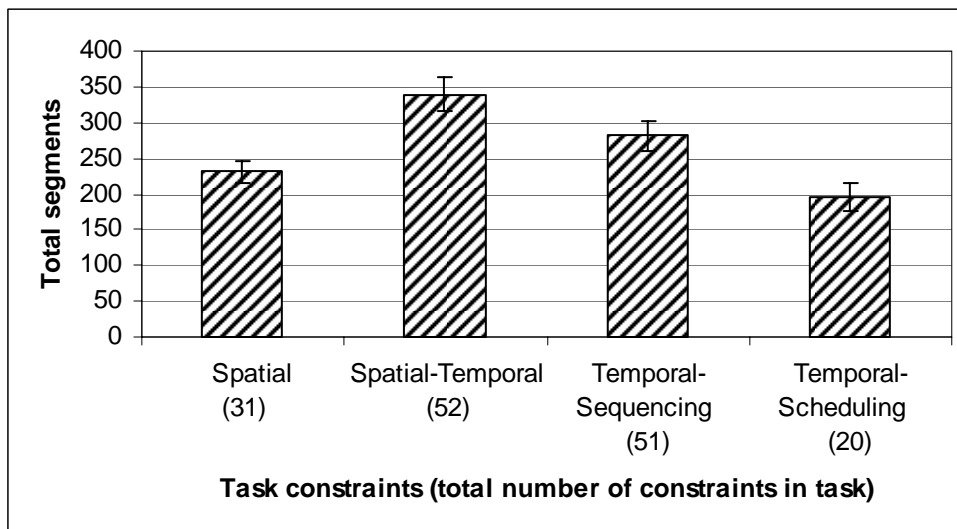*Figure 12.* Total number of segments produced per task (+/- SE)

Figure 13. Distribution of segments across the space-related, time-related and sequencing categories by task.
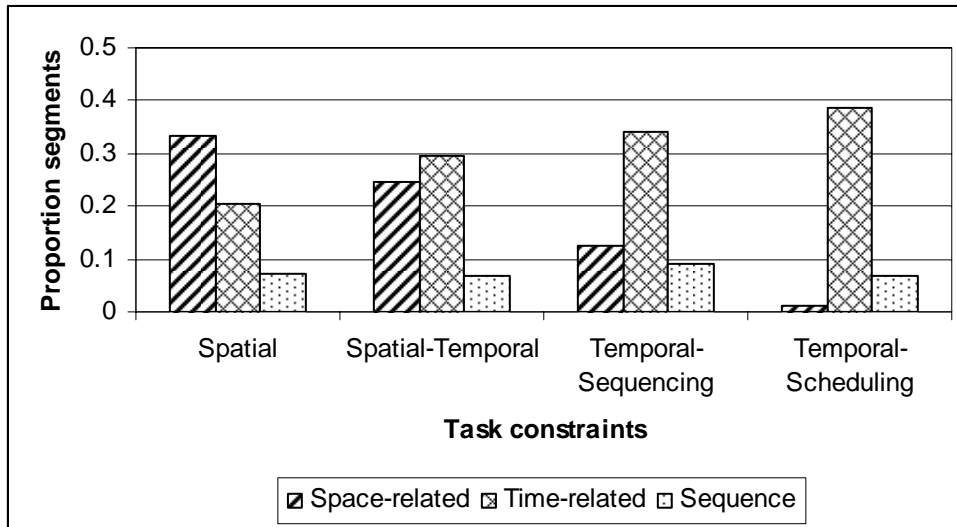
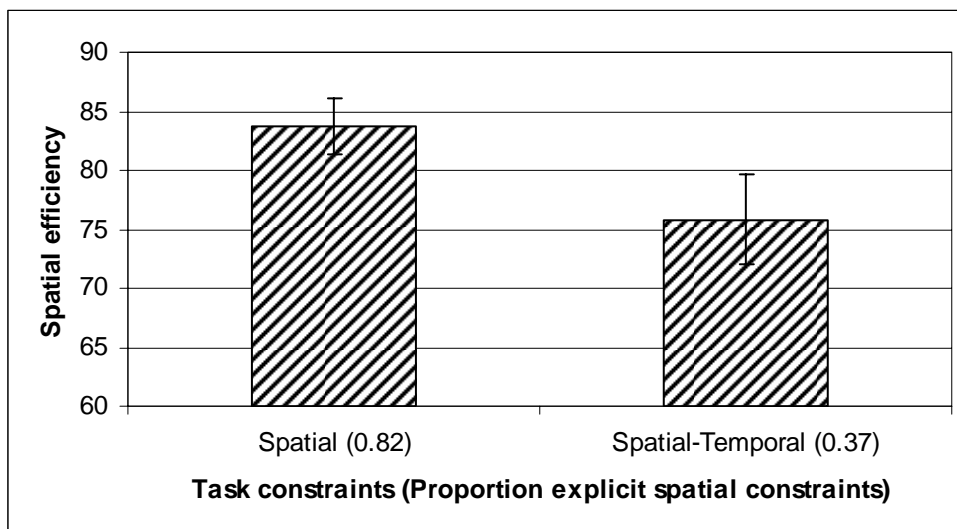*Figure 14.* Spatial efficiency spatial and spatial-temporal tasks (+/- SE)

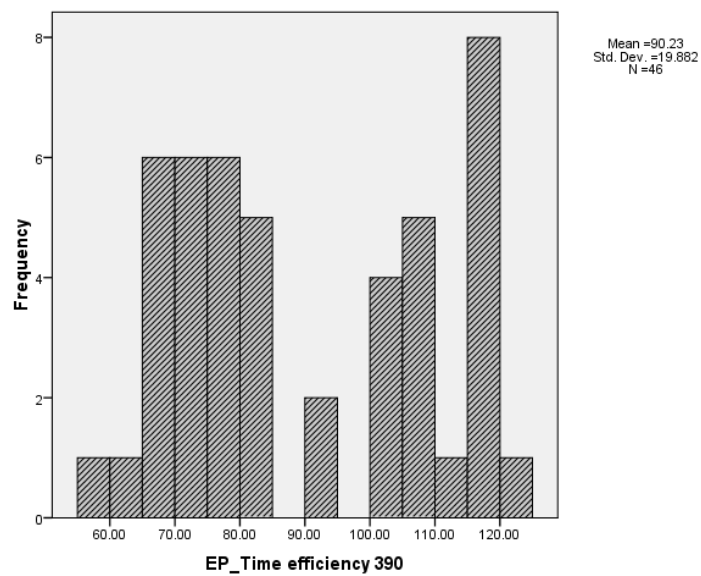*Figure 15.* Distribution time efficiency in spatial task.

Figure 16. Temporal efficiency spatial and spatial-temporal tasks (+/- SE)

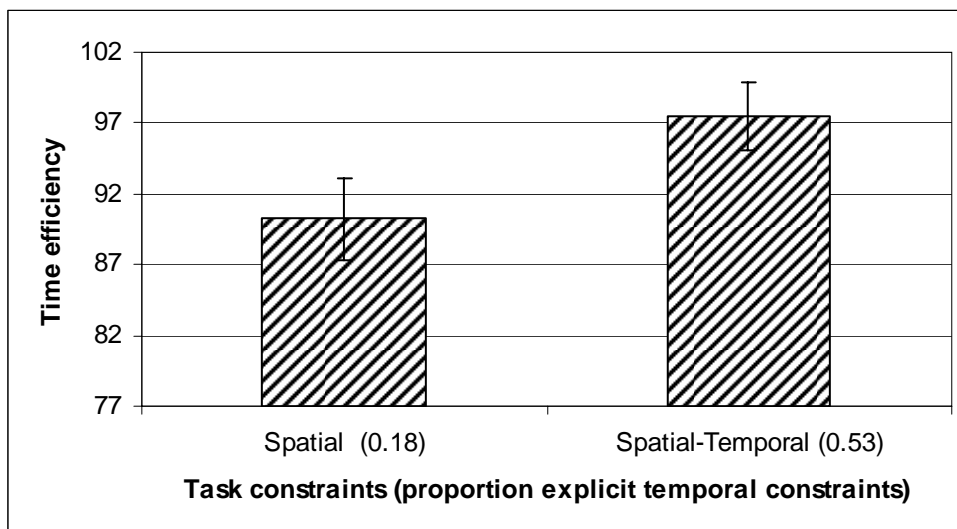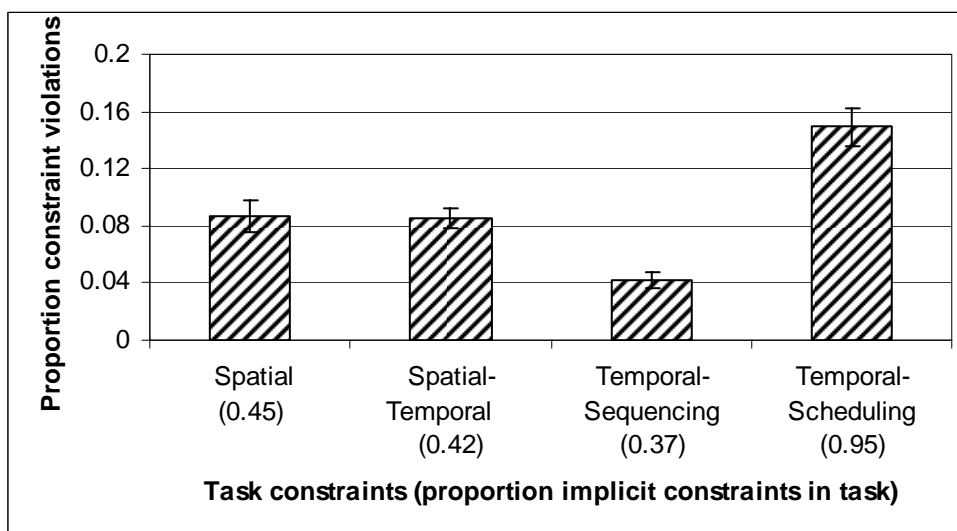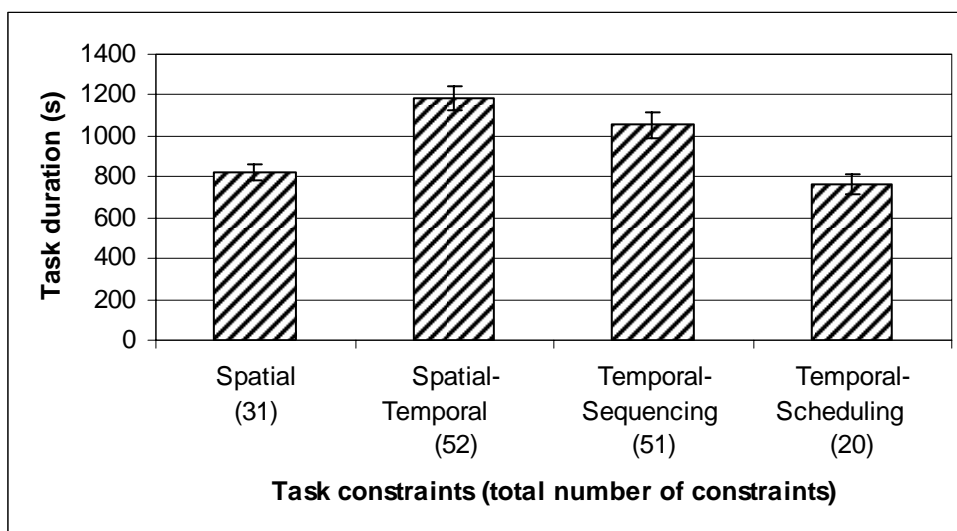*Figure 17.* Proportion of constraint violations by task (+/- SE)

Figure 18. Task durations by task (+/- SE)

Figure 19. Relationship between visuospatial memory in the Corsi test and sequencing in
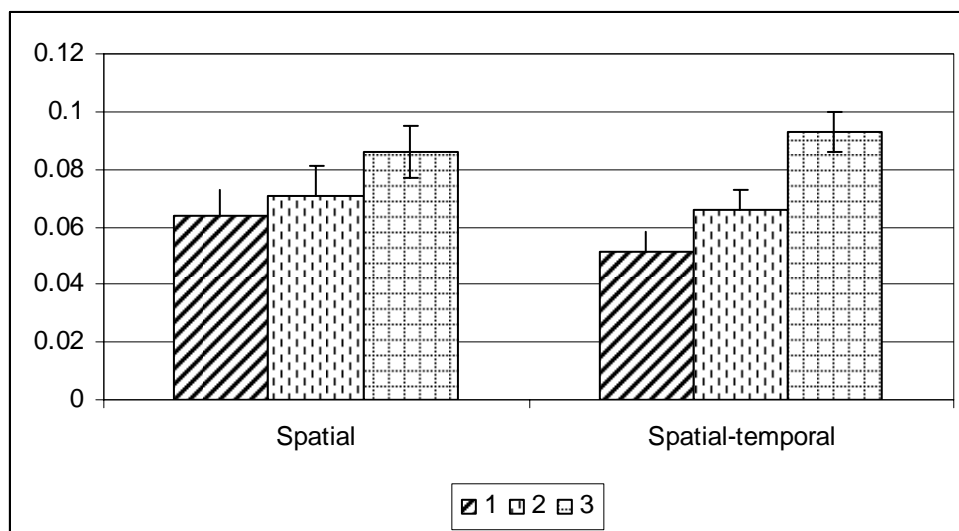
the spatial and spatial-temporal tasks.

Figure 20. Relationship between nonverbal fluency level and sequencing across tasks.

Figure 21. Relationship between verbal working memory and task duration across tasks

Appendix 1. Think aloud instructions for planning tasks

In this experiment we are interested in what you think about when you find answers to some of the tasks that I am going to give you. In order to do this I am going to ask you to THINK ALOUD as you work on the problem given. What I mean by think aloud is that I want you to tell me EVERYTHING you are thinking from the time you first see the task until you are finished. So I would like you to talk aloud CONSTANTLY from the time I present each task until you have say that this is your "Master plan". I don't want you to try to plan out what you say or try to explain to me what you are saying. Just act as if you are alone in the room talking to yourself. It is most important that you keep talking. If you are silent for any long period of time I will ask you to talk. Do you understand what I want you to do?

Good, now we will begin with a practice question so you can practice thinking aloud.

"How many windows are there in your parents' house?"

Appendix 2. Instructions for the errand-running task (spatial task).

This is an errand running task. Here is the town where you will be doing your errands. Take some time to see where the different stores are located. Here is the health club [experimenter points]. This is a book store [experimenter points to the book store on Benton Way]. If two stores are of the same type, they are indicated by the same picture. [Experimenter points to the dress shops on Belmont avenue and Jackson Avenue].

- You have just finished working out at the health club. It is 11:00 am and you can plan the rest of your day as you like.

- However, you must pick up your car from the Maple street parking garage by 5:30 and then head home.

- You'd also like to see a movie today, if possible. Show times at both movie theaters are 1:00, 3:00 and 5:00. Both movies are on your 'must see' list, but go to whichever one most conveniently fits into your plan.

Your other errands are

- Pick up medicine for your dog at the vet

- Buy stamps at the post office

- Check out two of the three luxury apartments

- Meet a friend for lunch at one of the restaurants

- Buy a toy for your dog at the pet store

- Pick up your watch at the watch repair

- Special order a book at the book store

- Buy fresh vegetables at the grocery store

- Buy a gardening magazine at the newsstand

- Go to the florist to send flowers to a friend in the hospital

Try to get as many of these errands done as you would normally manage.

Please write down your final plan here.

Appendix 3. Instructions for the amusement park task (spatial-temporal task)

In this task you will be planning a day at this amusement park. Here is a map of the amusement park. Take some time to see where the rides and entertainments are located. Here is the South entrance [experimenter points].

- You have just been dropped off at the South entrance to the park. It is 11:00 am and you can plan the rest of your day as you like.

- However, you will be meeting your friend Chris at the East Entrance at 2:00 pm and Chris will be babysitting 9-year old Jami. You will all be leaving the park together at 5:30 from the East Entrance.

- You all have swim wear with you.

- You'd like to try out windsurfing today. You can rent a board and get a lesson at 11:30 am, 12:30 pm or 2:30 pm.

Other things are:

- You need to have lunch at some point.

- Jami wants to go on the old-timer car track

- You would like to go on at least 2 of the 4 major rides (Anaconda, Python, Mamba and Tower Drop). All the rides go every 15 minutes.

- Chris wants to go on the Anaconda ride, and you will entertain Jami while Chris is on that ride. (Jami is not allowed to go on the 4 major rides).

- Jami likes to play in the water.

- You would all like to get ice-cream at some point.

- You would like to try out the inner tube maze

- Jami wants to get a 3-foot stuffed park mascot at the souvenir plaza

- Chris likes the video arcade

Try to get as many of these things into your plan as you would normally manage. Feel free to add more items to your plan.

Feel free to familiarize yourself with the map, note that there is a train that connects different parts of the park.

Here is a legend, which gives information on how long the different rides in the park take, and the train ride times.

You can use this paper to make your plan. Please remember to write "Masterplan" on the final plan.

Appendix 4. Instructions for cocktail party planning task (temporal-sequencing task).

It is 11.30am on Saturday morning and Kate has invited some friends to come round at 7 pm that evening for a cocktail party and some light desserts. Kate's friend, John has just arrived at Kate's house on the bus (he cannot drive). He is able to help Kate complete the list of "Things to do" before the party starts.

However, none of the tasks are in order so you must delegate each of the tasks to Kate or John. Write down your plans on the sheets available (using as many sheets as you wish to help you). Please remember to mark "Masterplan" in red pen on the final plan.

You should imagine that Kate and John are at Kate's house and that they receive your plan at 11.30am.   A map of the area is also provided to help you. The walking/ driving distances are also displayed on the map.

THINGS TO DO

John is due to play tennis between 2 and 3 o'clock at the sports centre. [TENNIS]

Kate's car has to be picked up from the garage at 12:30 (repairs have been paid for). [CAR]

5 chairs need to be borrowed from the neighbors who will be in between 5 and 5:30pm (15 minutes). [CHAIRS]

The living room should be vacuumed (20 minutes). [VACUUM]

The cocktails need to be mixed (1 hour 30 minutes). [COCKTAILS]

John forgot to bring the stereo around that he promised to bring. Kate will have to drive John home to collect it. [STEREO]

Kate needs 1 hour to get showered and dressed before the party starts. [SHOWER]

Kate has got no money and John cannot lend her any. She can withdraw money at the nearest bank machine at the supermarket in town. [MONEY]

A cake needs to be bought from the bakery and ordered at least 2 hours in advance before it can be picked up and paid for. The bakery shuts at 2:30pm. [PHONE BAKERS] [COLLECT CAKE]

Kate forgot to ask if any of the guests were vegetarians, so she needs to call them all to check beforehand so she knows what food to buy (30 minutes). [CALL FRIENDS]

The glasses and plates need to be put out after the living room has been vacuumed (15 minutes). [PLATES].

Ice cubes need to be made (15 minutes to prepare, and 7 hours to set). [ICE CUBES]

There is no food or alcohol in the house. The party food needs to be bought at the supermarket in town (1 hour needs to be allocated for time spent in the supermarket). [SUPERMARKET]

Appendix 5. Instructions for spring break planning task (temporal-scheduling task).

This task is planning your time during a hypothetical Spring Break.

Here is a chart with your spring break times. You took the weekend off and blew most of the money you had saved up for Spring break, so you have money for basics, but not much else. Now you have a week left. Monday [point to Monday] through Sunday {point]. The time of day is indicated here [point]. Each of these sections represents an hour.

Here are the things you would like to do, or have to do during spring break.[put the cards down as you mention the tasks]

You have a dentist appointment for a root canal on Thursday at 9:00 am.

You have a 10 page research paper due the Monday after spring break at 9:00 am, which you have done no work on yet.

You want to wash your car.

You promised your grandmother that you would clean and organize her garage.

You have to buy a birthday present for a good friend.

You can make extra money by doing filing work for your uncle, but that is optional.

You can hang out with friends.

You have a friend coming in from out of town, and you may go to New York City with that friend, they've never been there.

There are three movies that you can go see in the movie theater.

These cards each represent an hour of the activity. Use however many you think you'll need for the activity. If you run out of cards you can put them down so that they cover more than one time slot.

Appendix 6. Coding scheme space-time-sequence

o The main aim of this coding scheme is to classify the thoughts in the planning

   transcripts as being either space-related, time-related or related to something other.

o The time category is divided into anchored (conventional) time, common time,

   duration and other

o The space category is divided into location, distance and other.

TIME

Anchored time		
Explanation	Subcategories	Examples
Anchored or conventional time, is time that is related to some fixed point.	**24 hour** 8 am, fixes the time at a location on a 24-hour clock.	8 am, 9, 11:30, midnight, noon
	Week Friday fixes the locates the time in a week,	Monday, Tuesday, Wednesday etc.
	Month July fixes the time within the year	January, February, etc.
	Year 1926 fixes the time on a calendar.	1994 etc.
Common time	**Index**: Specifies a point in time or planning sequence.	'at this point' 'that time' 'now'
	Sequence Anything to do with time as a	'later', 'then I will…' 'next' 'I'll start with', 'I'll do that

	sequence, or the evaluation of the time in the sequence.	early' 'I'll do that first/last', 'number 1', 'number 2' (as in an ordered list)
	Meals Time ordered according to meal times	Lunch time (*not* 'lunch' or 'dinner', but meals specified as times)
	Day Time sequenced according to the sequence of the day	'early in the day' 'in the afternoon' 'morning' 'in the evening' 'I'll work nights'
	Week – time considered from the perspective of the week frame	'On the weekend', week day, 'later in the week', 'some other day'
Duration		
	Absolute: duration as some quantity (does not have to be exact)	'5 hours' 'all Monday' 'all those days' '20 minutes' 'rest of the day' 'a little bit' 'more time'
	Evaluation (positive or negative)	'too long' 'that'll be quick'
	Interval Anchored (either between anchored times, or other time points) duration as an interval between time	'from 11 to 2', 'let's say from…' 'until about 6' 'until 12 or 1' 'starting at'

	points	'until…'
	Neutral – some mention of duration without specification, or concern with duration	'that will take' 'how long will it take?' 'time slot' 'per hour'
	Temporal motion – some action mainly concerned with time	'run' 'hurry'
Note: if they're counting hours (in SB), if they name the actual hours 8 o'clock, 9, 10 then it's anchored 24, if they're counting 1, 2, 3, it's time other.		
Other	**Stuff that is time related** but not in the other categories	'post office is closed' 'time to start' 'when is that' 'wait a minute' 'I'm a morning person' 'I got class at' 'I'm scheduled to' 'anytime'
SPACE		
Location	**Indexical** – identifies a specific place with a 'pointing' word,	'it's here' 'there it is'
	Absolute – if they name a place, and it looks like they're naming the place NOT THE ERRAND or TASK	'where is the vet', 'ok, the grocery store' 'Ok, I'm at the bookshop'
	Relative – if they specify some location or relation between locations.	**Relative to current location** 'that's across the street from here' it depends

		on the narrative
		Relative to other location 'the post office is by the pet store' 'what else is near there'
		Relative to route – 'what's along the way'
		Relative to street – DON'T USE
		Relative to map – 'Oh, that's up there'
	Directional motion – whenever the focus is very much on the motion	I'll head to the grocery store' 'walk to the newsstand'
Distance	**Absolute**	'5 blocks'
	Evaluation (pos or negative'	'that's really far' 'close by'
	Neutral	'how far is that'
OTHER	**EVERYTHING ELSE – specifically mentions of the task**	

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