Multitasking as a choice: a perspective

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 **Abstract**

Performance decrements in multitasking have been explained by limitations in cognitive capacity, either modelled as static structural bottlenecks or as the scarcity of overall cognitive resources that prevent humans, or at least restrict them, from processing two tasks at the same time. However, recent research has shown that individual differences, flexible resource allocation, and prioritization of tasks cannot be fully explained by these accounts. We argue that understanding human multitasking as a choice and examining multitasking performance from the perspective of judgment and decision making (JDM), may complement current dual-task theories. We outline two prominent theories from the area of JDM, namely Simple Heuristics and the Decision Field Theory, and adapt these theories to multitasking research. Here we explain how computational modelling techniques and decision-making parameters used in JDM may provide a benefit to understanding multitasking costs and argue that these techniques and parameters have the potential to predict multitasking behavior in general, and also individual differences in behavior. Finally, we present the one-reason choice metaphor to explain a flexible use of limited capacity as well as changes in serial and parallel task processing. Based on this newly combined approach, we outline a concrete interdisciplinary future research program that we think will help to further develop multitasking research.

*Keywords*: multitasking, task-switching, judgement, decision-making

**Multitasking as a choice: A perspective**

Performing two or more tasks at the same time is a constant requirement in daily life and science is trying to understand the core mechanisms both facilitating and limiting human multitasking capacity (Fischer & Plessow, 2015; Pashler, 2000). Think of the dangers associated with writing a text message or making a call while driving. It is estimated that 1.3 million people yearly die in road crashes (World Health Organization, 2015) and it is likely that many are attributable to multitasking challenges. However, think of the following scenario: you are driving to a meeting, have made the responsible decision not to take the incoming call and, upon arrival, you realise that the content of the call was the last-minute cancellation of the meeting. In this instance multitasking would have been beneficial, and it seems important to understand if and under which conditions multitasking is possible. What this example suggests is that independent of whether individuals show complex behavior in real-life scenarios, or downscaled behavior in experiments like button-pressing, they may encounter both choices and serious limitations in cognitive control that may lead to performance problems.

In this paper, we reflect on the question of why and how individuals prioritize tasks and options, as well as on cognitive control and information processing[[1]](#footnote-2) in *multitasking* and in *judgment and decision making* (JDM). We will further reflect on different performance measures. In common with reaction times as a measure of performance decrements in multitasking, decision times have been examined in JDM, facilitating a straightforward comparison between the two perspectives. Beyond that, JDM also offers useful methods to further understand, differentiate, and model performance decrements. For example, computational models can help to predict acute changes and dynamics in reaction times, and decision-making parameters like dynamic preferences can help to predict probabilities of choices, so both allow to *anticipate* or *predict* individual differences in behavior. This contrasts with traditional multitasking research, which instead of predicting behavior and individual differences, often categorizes individual behavior post-hoc on the basis of data already collected (Reissland & Manzey, 2016). Multitasking research often neglects the possibility that two tasks may differ in valence or attractiveness to the participant, and only rarely takes into account processes of choice behavior like choices of online order control (Hendrich, 2014; Luria & Meiran, 2003), task biases or choice reaction times (Fröber & Dreisbach, 2017).

We conclude that even though current well-controlled multitasking paradigms provide a valuable basis to specify potential sources of resource limitations, factors influencing decisional and pre-decisional processes as well as individual differences in multitasking are often neglected. We suggest that JDM approaches offer useful methods and parameters to extend our understanding of individual differences and flexibility in multitasking, and to re-evaluate elaborate approaches such as bottleneck or resource capacity sharing models. We therefore aim to provide a new perspective that outlines multitasking as a choice. We will start by illustrating core concepts of the fields of multitasking and JDM research that we consider most relevant for developing a JDM perspective on human multitasking. We then cross-fertilize findings and theories from JDM and multitasking research by presenting the concept of prioritization and explaining how cue-validities and decision parameters enrich this concept, and finally outline a concrete future research program.

**Multitasking**

Multitasking refers to the execution of two or more tasks that are performed in the same time window, either simultaneously or in rapid succession. It is typically investigated in dual-task or task-switching paradigms (for an overview see Kiesel et al., 2010), or in paradigms that combine properties of both and require participants to process both tasks in parallel while rapidly alternating between them (Kiesel & Dignath, 2017). In all these procedures, it is hypothesized that a previously, or co-instantaneously, executed task may influence execution of a subsequent or simultaneously task (respectively, task switching and dual task).

When describing multitasking as a choice we focus on those paradigms that leave some room for decisional processes by the participants. For example, we include dual-task paradigms that allow for unequal attention allocation between tasks and the prioritization of one task over another, or task-switching paradigms that allow for a choice of which task to begin with or for a choice of the switching moment. We do not include PRP designs (*Psychological Refractory Period*, De Jong, 1995) where participants’ choice is fully constrained by a delayed onset of the second task, nor do we consider cued or sequenced task-switching paradigms that either dictate the moments of switching or dictate which task to begin with. These fall short of the scope of the choice perspective in multitasking because they preclude individual choice. However, we presuppose that this restriction is valid given that many real-world multitasking or task-switching scenarios allow for variable prioritization of one task over the other, and the growing interest in research using paradigms that accredit participants with more degrees of freedom.

**Understanding cognitive control in multitasking**

A number of comprehensive theories, which can be characterised as *structural, strategic*, and *flexible*, have explained the emergence of dual-task interference on cognitive levels (Fischer & Plessow, 2015; Pashler, 2000). Traditional bottleneck theories claim the existence of a *structural* central processing entity that processes information in a strictly serial fashion. Whereas Welford (1974) and Pashler (1984) defined limitations at response selection as a structural bottleneck (see also De Jong, 1995, for motor bottleneck approaches), others argued that bottlenecks can be *strategically* implemented in early, middle, or late stages in the information processing stream (Meyer & Kieras, 1997). *Strategic* resource scheduling leads to a volitional but sequential distribution of attention to both tasks that need to be performed. Models arguing for *flexible* capacity sharing between resource-limited stages and parallel processing, posit an overall capacity limitation, with attention being allocated in global unspecific ways (Kahneman, 1973) or to modality-specific capacities (Navon & Gopher, 1979; Wickens, 2008). Other capacity sharing approaches assume a capacity limitation at central stages that can be flexibly shared between the two tasks (Tombu & Jolicœur, 2003). Critically, the way in which the capacity is shared between the two tasks may be determined by instructions, because instructions change the amount of capacity that is allocated to each of the two tasks (Lague-Beauvais et al., 2015).

Task-switching studies represent a special case within multitasking because the two tasks are typically not executed simultaneously but in a sequence and participants switch back-and-forth between tasks (Kiesel et al., 2010; Monsell, 2003). Performance decrements in task-switching paradigms (*switch costs*) typically occur after changing tasks and have been attributed to a reconfiguration of the new task set (e.g. Rogers & Monsell, 1995), from the previously activated but now irrelevant task set (e.g. Allport, Styles, & Hsieh, 1994), or to an additional inhibition process needed to de-activate the previously active task set (e.g. Strobach, Liepelt, Schubert, & Kiesel, 2012). In cued task-switching studies the experimental setup externally predetermines the scheduling of task switches and/or repetitions and does not leave any room for choices or self-organization. Instead, in voluntary task-switching paradigms participants choose the task they would like to begin with and the moment of switching and often only need to abide by the instruction of random task choice, as if flipping a coin decides which task to do next (Arrington & Logan, 2004; Mayr & Bell, 2006; Yeung, 2010). More recent studies have developed this design further by providing a preview of the requirements of the currently non-processed task to optimize performance on a stimulus-driven rather than a memory-driven choice (Kiesel & Dignath, 2017). As we will elaborate later, the decision of when to switch may be influenced by different external cues like perceived salience or task difficulty on the first trial or the presentation of specific items or reward expectations prior to the choice (Arrington & Weaver, 2015; Fröber & Dreisbach, 2016; Kessler, Shencar, & Meiran, 2009; Kiesel & Dignath, 2017), and by different internal cues such as the current load on the cognitive system (Demanet, Verbruggen, Liefooghe, & Vandierendonck, 2010; Kiesel & Dignath, 2017).

**Judgment and Decision Making**

As indicated above, multitasking literature casually describes and integrates decision and choices in their research (e.g., the choice of when to switch). In the judgment and decision-making (JMD) literature, decisions are the main core of investigation and are described as a judgment of what to do (Newell, Wong, Cheung, & Rakow, 2009). JDM models can be classified as models that are either specific to environments of risk where probabilities of each outcome are known, or specific to environments of uncertainty where these probabilities are not known (Gigerenzer & Gaissmaier, 2011). JDM models may be classified as static or dynamic, with dynamic models being those that describe how a person’s preferences evolve over time. Further, models differ with regard to the type and amount of information processing (i.e., serial, parallel and rule-based processing). In this paper, we focus on two JDM theories: 1) Simple Heuristics and 2) Decision Field Theory (DFT). These two central theories differ in respect to information processing such that simple heuristics favor serial and DFT favors parallel information processing. This separation was the starting basis to explore the cross-fertilization between JDM and multitasking, because serial accounts such as the bottleneck account and parallel accounts such as resource capacity sharing models are well discussed in the multitasking literature (Fischer & Plessow, 2015).

**The simple heuristic approach as an example of serial processing**

The simple heuristic approach predicts that people choose between two options based on rules of thumb, using only a limited amount of information. Heuristics consist of a search, stop and decision rule, and are often referred to as one-reason decision making or simple rules of aggregation, because the final choice relies on one reason only. One example for one-reason decision making is the Take-The-Best heuristic (Gigerenzer & Goldstein, 1996). Here the most valid cue is first used to decide between two options (search rule). If this cue is able to discriminate between the two options, no further cue is used (stop rule), and the option with the higher cue-value is chosen (decision rule). Which cue is used first is determined by cue validity defined as the number of correct choices when the cue is used, divided by the total number of choices in which the cue was applicable (Gigerenzer & Gaissmaier, 2011). Both search, stop and decision rule as well as cue use are considered strictly serial processes.

**Decision Field Theory as an example of parallel processing**

The Decision Field Theory (DFT) is a probabilistic model that provides evidence for flexible choice. It predicts that people’s choices in one situation are not always the same as in another identical situation because they are influenced by different parameters (for a list of all parameters see Busemeyer & Townsend, 1993). One basic principle of DFT is *dynamic inconsistency,* which describes a dynamical change of option preference over time. For instance, in option-generation paradigms in which you freely generate possible options sequentially, you may prefer an option that came to your mind first but after thinking about it for a while you may favor another option even if the situation has not changed. DFT is a choice model that falls into a class of accumulation models. Such models suppose that a choice is made after evidence in favor of one option has passed a certain threshold. The threshold parameter defines how much cumulative information a decision maker needs before choosing an option and therefore defines the time it takes to make a decision. The threshold depends on multiple individual and/or environmental factors such as a person’s experience with or commitment to an option, or to differences in personality (Scheibehenne, Rieskamp, & González-Vallejo, 2009).

Besides the threshold parameter, there are two other parameters that are important to consider. The attention weight parameter reflects how much relative attention individuals need to provide to satisfy each attribute in a decision context. The attention weight parameter is initiated by the decision makers’ internal change of attention or by newly introduced information that lead to a switch of attention (e.g. Posner, 1980). However the more information is extracted and accumulated from one attribute the more likely is a switch of attention towards a new attribute (Diederich, 1997).

The initial preference parameter represents individual biases towards options. Individuals may have preexisting preferences for one option before even considering information about all options. In unfamiliar tasks and experimental settings, the initial bias parameter is often set to zero to reflect an equal preference towards all options, but learning and feedback (e.g., rewards) can influence the perception of an option and change preference towards one of the options. In turn, if two choices have different starting preferences, people under time pressure may rely heavily on the option with the higher preference and thus reduce choice reaction times (see Raab & Johnson, 2004 for an example).

**Cross-fertilization between multitasking and JDM**

In reviewing the literature on multitasking and JDM it has become clear that there are similar aspects that might benefit from cross-fertilization when we view multitasking as a choice (see also Figure 1). For instance, both fields differentiate aspects of cognitive control, as well as the influence of internal and external cues on information processing and outcomes (i.e., decision or multitasking performance). We aim to illustrate commonalities between the two accounts and to demonstrate potential transfers from one approach to the other[[2]](#footnote-3). We propose to convey the idea that choice in multitasking can be interpreted as the prioritization of one task over another, which is influenced by cue-validities and search rules as defined by the heuristic account and dynamic preferences as defined by DFT. We suggest that dual-task and task-switching paradigms may benefit from computational modelling, as done in JDM, for describing, explaining, and predicting reaction times. Computational modelling would allow researchers to extend existing perspectives on multitasking by providing specific predictions about the probabilities of task-switching from trial to trial, and by adding new dependent variables to multitasking like choice probabilities.

*Figure 1 here*

**How prioritization in multitasking can be explained by cue validities**

It has been suggested that cognitive control and “interference processing depend on the ability to set task priorities” (Stelzel, Brandt, & Schubert, 2009, p. 247). We support the claim that prioritization can be defined as the allocation of more attention to one of two tasks (cf., Pashler, 1994), but would argue that attention allocation is based on the evaluation of cue-validities. The use of cue-validities can be inferred from attention allocation, with more attention being allocated to cues with higher validities. For example the STOM model (*Strategic Task Overload Management*), states that multitasking performance and switching behavior can be explained by attention allocation towards different task attributes that we would equate with cues (Wickens, Gutzwiller, & Santamaria, 2015). The five task attributes central to the model are 1) salience, 2) priorities, 3) interest, 4) attribute weights, and 5) task difficulty. For instance, they argue that salience (e.g., visual attractiveness) of a stimulus serves as a reminder to perform the alternative task, and determines whether participants switch or repeat the task or which alternative they choose when there are more than two options. Likewise they exemplify that priority has shown to change a theoretical 50:50 preference ratio of dialling:driving, to a 33:67 preference ratio in favour of driving when driving was emphasized in the instruction (Janssen & Brumby, 2010).

In their conclusion however, Wickens and colleagues (2015) concede that in multitasking “more studies are needed to understand the relative ordering or dominance of attribute weights” (p.82). As argued above, cue-validities could help to answer how attribute weights are ordered and how the choice to prioritize or switch tasks comes about. In JDM, attention allocation towards cues is typically measured by gaze and kinematics. For example, a study applying simple heuristics measured visual fixation times after a saccade as a proxy of attention in an allocation task. Attention towards the most valid cue was shown to occur earlier in the decision process for experts who had learnt the cue validities (Glöckner, Heinen, Johnson, & Raab, 2012). Another study by Koop and Johnson (2013) measured gaze and hand-kinematic trajectories towards one of two options on a screen to illustrate response dynamics in preferential choices of gambles. Choices in these gambles entailed different risks: Gamble A (left side) provided participants with information about the probability of winning and the profit (e.g. respectively 80 % and $ 60). Gamble B (right side) provided participants with different probabilities of winning and a different profit (e.g. 90 % and $ 50). Curvatures in trajectories and gaze were interpreted as indicators of choice processes. Keeping the response trajectories in the midline between the two gambles and then moving directly to one of the gambles occurred when one attribute differentiated between A and B was interpreted as a one-reason choice process (e.g. simple heuristic). In contrast, if the trajectory first moved in the direction of one gamble but then moved in the direction of the other gamble, this was seen as evidence for accumulator models (e.g. DFT) with preferences for options being rather dynamic over time. Results indicate that curved trajectories and gaze pattern, as well as movement times, differed depending on whether participants chose a risky or safe option and thus confirmed situation-specific use of choice processes related to simple heuristics and DFT. To sum up, JDM and multitasking research both would agree that prioritization is a matter of attention allocation, however, here we argue that multitasking literature would profit from extending the theoretical view of task prioritization by incorporating choices grounded on cue-validities. Even though gaze and kinematics are not unknown variables to multitasking research, using these methods/measures to evaluate cue-validities would shed a new light and extend multitasking research beyond the standard measure of errors and reaction time differences.

In addition, it has been argued that cues can also be generated within a person, not only in the task environment (Glöckner & Betsch, 2012; Meyer et al., 1997), with cue-generation varying with working memory load or individual differences in cognitive control capacity (Arrington & Weaver, 2015). There is however some agreement, that internal cues are less able to minimize costs and that the relationship between choices and performance rather depends on the use of external cues. For instance, Borst and colleagues (2013) showed that people rely on external cues when they were perceived as highest in validity and as the fastest option, and Leonhard et al. (2011) demonstrated that people strategically choose the order of task processing dependent on the tasks’ perceived difficulties with optimization being especially pursued for time-consuming tasks. Others also showed that performance in the primary task suffered when the sequence of upcoming tasks was made unpredictable and thus participants were unable to make meaningful use of cues in ordering tasks (De Jong, 1995; Sigman & Dehaene, 2006; Szameitat, Lepsien, Von Cramon, Sterr, & Schubert, 2006).

Simple heuristics and the use of cue-validities have rarely been applied to dual-task conditions. An exception is the Tardast computer scenario, which mimics human multitasking demands (Neth, Khemlani, Oppermann, & Gray, 2006; Shakeri & Funk, 2007). In the Tardast task, six vertical bars represent six competing tasks that require parallel resource allocation. Over a specific period of time, participants have to control the height of the bars to a certain threshold by pressing buttons underneath the bars. Not attending to a bar by lifting the button causes the bar to drop, resulting in penalties when it falls below the zero line. For participants, it is impossible to keep all six bars at optimum level, so different bars have to be prioritized all the time. The feedback received for this performance was either single-task specific (single bar performance) or a summary of all bars as an aggregate measure of overall performance. Those participants who received task-specific feedback did not only significantly outperform those participants who received summarized feedback, they also reached performance levels of artificial machine operators after some practice. Hence, it seems that task-specific feedback served as a cue that enabled participants to prioritize a specific task, leading to better performance. Simple heuristics would interpret this result as participants’ inability to break-down summarized feedback into specific search rules. From a deterministic bottleneck approach, it is challenging to explain these performance differences. Structural bottleneck accounts would predict that, because only one information could be processed at a time and any further information needs to queue until the processing entity is freed, a single unit of summarized feedback would go together with less processing load than six separate units that have to be processed sequentially. Opposed to this, simple heuristics argue that specific feedback is needed to apply the right search rule identifying the most valid cue and thereby improving performance. Hence, we conclude that specific and adaptive feedback structures (Liepelt, Strobach, Frensch, & Schubert, 2011; Neth, Khemlani, & Gray, 2008) that follow rules of simple heuristics can improve multitasking performance and learning.

**How prioritization in multitasking can be explained by decision field parameters**

As outlined, Wickens and colleagues (2015) proposed that one important need in future research is to explain ordering of task attributes. They also stated that, although task-switching tendencies are being reported, it is necessary to further understand *why* some participants are more likely to abandon a task as time goes on (“time-on-task”, p. 82). DFT predicts that information accumulation needs to pass a certain threshold determining and predicting how long individuals take for a decision. This aspect of timing is important because, even though multitasking accounts attempted to model individual response patterns based on reaction times and distributions post-hoc (Reissland & Manzey, 2016), the attempt to predict reaction times is less well developed. Hence, we suppose that DFT-parameters, and especially multi-attribute models, may be well-suited for understanding the dynamics of participants’ trial-to-trial behavior in multitasking and for predicting reaction times. In particular, the MADD (*multiattribute dynamic decision model* with geometric choice distribution, Diederich, 1997, for other distributions see 2016), states that the decision maker uses attributes to anticipate and evaluate all possible consequences that might occur after choosing an option. The longer the decision maker abides by an attribute, the lower is the rate of information to extract from it and the more likely is a switch to another attribute. Applying this to task-switching behavior would imply that switching to another task or attribute becomes more likely the longer the participant has been repeating one task or using one attribute. Thus, the MADD would help to predict switching probabilities based on previous trials and consider transition probabilities from trial to trial, which makes it a useful extension to understand switching behavior.

Another important DFT parameter helping to understand prioritization is dynamic inconsistency, because it considers dynamic changes in preferences. A study by Nijboer and colleagues (2013) for instance has manipulated initial preference in a self-determined dual task. Participants were given a fixed primary task that had to be continuously executed (multicolumn subtraction) but were free to choose the secondary task at the beginning of every trial (tone-counting vs. trackball task). Even though participants were trained on all combinations of primary and secondary tasks prior to the experiment, initial preference shifted towards that task that was most promising to reduce interference. Ergo, people seem to be generally able to avoid high interference conditions and make correct judgments about dual-task costs relative to the experience and time they have with a task. However, Nijboer and colleagues (2013) also report large individual differences in decision behavior, which they have interpreted as a result of participants’ different utility estimations of task choice. DFT would however accentuate that differences can be assigned to individual differences in personal preferences and not to task characteristics per se (for a discussion about interactions of personal and task factors in multitasking see Fischer & Plessow, 2015).

Dynamics of preferences could also be important for voluntary task-switching paradigms, if we understand prioritization as a result of learning across trials and consider the influence of experience *during* task execution. Studies have shown that people develop the small but consistent preference to repeat harder tasks (Yeung, 2010), possibly because between-task competition influences choices between easy and hard tasks. Increased investment in hard tasks may result in larger switch costs to easier tasks making it hard to leave the harder task (Poljac & Yeung, 2014). DFT would argue that, even though preference towards all tasks is evenly distributed at the beginning of an experiment, it might shift towards one task due to experience and feedback during the first trials. Such trial-to-trial dynamics explain individual differences in changes of preferences or decision thresholds because they consider learning and rewards over trials. Regarding results of Poljac and Yeung, DFT would argue that participants with a stronger preference for harder tasks repeat their choice, because a hard task in the following trial is already closer to a decision threshold than an easier task would be.

**Understanding the role of automatic processing in multitasking from JDM**

Similar to multitasking, JDM has addressed the role of automatic and conscious information processing for performance (Newell et al., 2009). On the one hand, the search for cue-validities has been considered as controlled and serial processing that requires conscious thought (e.g. Baron, 2000). On the other hand, it has been argued that there is substantial influence of salient stimuli activating brain networks automatically (Glöckner & Betsch, 2008). Multi-attribute judgment models aim to overcome this dissociation by understanding decision processes as an interaction between automatic and controlled processing, allowing for parallel processing. It has been suggested that stimuli can activate a set of associations and alternatives from memory which is directly accessible when it has been well-learnt and frequently used. Relying on such association sets usually leads to conscious but economic and effort-saving processing, yet with solid final decisions. We suggest that effective multitasking and minimized mental effort does not only occur when one task is automatized and freed from conscious processing (Ruthruff, Hazeltine, & Remington, 2006), but also when an adequate amount of cognitive resources and cues is available to access associations with a task (Katidioti & Taatgen, 2014) and people are able to flexibly adjust to contextual information (Fischer & Plessow, 2015).

**Summing up: Multitasking behavior as rule-based judgments and one-reason choices**

Novel experimental approaches in multitasking have begun to create task environments that combine characteristics of task-switching and dual-tasking. Just like the Tardast task, the free-choice paradigm for instance allows for parallel processing but requires participants to alternate between different tasks (Kiesel & Dignath, 2017). In the free choice paradigm, participants work on four tasks whose order they are free to determine. Crucially, while they work on one task they can see the content of the three other tasks for the upcoming trials. In this way participants are able to decide on task-switches based on stimulus information rather than their memory of the three other tasks. This development does not only mirror the demand for choice-settings that resemble the manifold potential choices in real-life, it also shows the need for a more unified model of processing, away from the strict segregation of serial and parallel processing. This need has been discussed in both the multitasking and the JDM domain (Fischer & Plessow, 2015; Kruglanski & Gigerenzer, 2011). While Fischer and Plessow (2015) describe the weighted interaction between serial and parallel processing as an adaptive behavior, Kruglanski and Gigerenzer (2011) concretely suggest that dual-process theories should no longer be treated separately, but should be integrated and subsumed under the term rule-based judgments. Such unified models have fewer degrees of freedom (e.g. in number factors and of potential interactions) and serve principles of parsimony which have been claimed by Occam's razor (Blumer, Ehrenfeucht, Haussler, & Warmuth, 1987). A more unified understanding of multitasking processing, could foster the development of new paradigms that better simulate real-life behavior and multitasking costs. To approach this unified understanding, we suggest a one-reason choice metaphor. This metaphor does not intend to replace good theorizing, but to extend previous perspectives. A one-reason choice metaphor would argue that prioritization of tasks and the application of serial or parallel processing is dependent on one reason only. As outlined above, the one-reason could be the most valid cue a person perceives, cue recognition, their experience with a task, (ir-)rational preference, or any other reason. Per our one-reason choice metaphor humans may use one reason to decide a) which task to prioritize (allocate more attention to) in multitask situations (Busemeyer & Townsend, 1993) and b) whether serial or parallel processing, or ”rule-based” processing is most beneficial in a multitasking situation (see Kahneman, 1973).

According to a) a one-reason metaphor would be used to describe how humans handle choices between two or more tasks in multitasking situations. Task choice in multitasking would be facilitated by a higher preference towards one task, and choice for tasks with higher starting preference would be especially pronounced under time pressure. If we assume that also voluntary task-switching paradigms are influenced by initial preference, trial-to-trial experience, feedback or rewards, dependent measures like gaze, kinematics or reaction times could be predicted, interpreted, and changed by different preferences. Therefore, particular preferences and any cues for one-reason choices are important to consider for the design of multitasking experiments. This approach will extend traditional multitasking experiments that have constrained choices and neglected preferences by pre-determined stimulus onsets (e.g. PRP-designs) or instructions.

According to b) one-reason metaphors could also be used to describe how people use serial and parallel processing in multitasking situations. The simple heuristic approach postulates serial processing just like a structural bottleneck, so we would infer that increased consideration and usage of cues, and their validities, would be associated with longer reaction times in dual-tasks. In contrast, DFT postulates parallel processing just like capacity sharing accounts, so we would infer that the number of cues would not (considerably) alter reaction times. In addition, cue validities could predict individual reaction times or flexibility in task scheduling. The added value of a one-reason choice metaphor is a more flexible and adaptive way to use information when confronted with multitasking requirements. At the same time, it integrates so far unrelated dual-task and task-switching perspectives by focussing on their common ground, which is that cues are used to decide which task to prioritize or when to switch tasks. Finally, it helps to elaborate further on individual differences which shall be discussed as a starting point for future research programs in the following section.

**From Metaphors to Research Programs**

We argued that a new perspective in human multitasking would be to describe multitasking as a choice. We used two theories of decision making that have not been consistently applied to multitasking before, but which may explain flexibility of multitasking behavior and individual differences in performance and thus provide a showcase of rather flexible processing when deciding between two or more tasks. In multitasking research, the role of individual differences has been discussed for instance on the background of serial and parallel processing. Parallel processing was found to be promoted through divergent thinking and the use of multiple cues (Fischer & Hommel, 2012), and was increased for participants in negative mood (Zwosta, Hommel, Goschke, & Fischer, 2013) and acute stress (Plessow, Schade, Kirschbaum, & Fischer, 2012), possibly because parallel processing is perceived as less effortful (Kool, McGuire, Rosen, & Botvinick, 2010; Lehle, Steinhauser, & Hubner, 2009). Moreover, frequent multitaskers are supposed to be more impulsive and sensation seeking (Ophir, Nass, & Wagner, 2009), an argument that has been discussed for fast decisions as well (Guitart-Masip, Duzel, Dolan, & Dayan, 2014). Such traits seem to bias people to use more parallel processing even though it might not be optimal behavior. A promising line of research towards individual differences, that also taps into decision making behavior, targets the so called ‘super-taskers’ (Medeiros-Ward, Watson, & Strayer, 2015). Super-taskers do not exhibit any (or hardly any) dual-task costs and it has been suggested that parallel processing is the most efficient choice for them. In future research, it would be interesting to test how super-taskers behave when they are free to choose between serial and parallel task processing and how cues and different cue-validities change their behavior.

So, how could we incorporate cues, cue-validities, preferences, and other decision-making parameters in a multitasking paradigm? Let us work around a dual-task paradigm that has been recently published by Janssen and Brumby (2015). In their setting, participants work on two tasks, with one task being temporally occluded when they are not attending to it. The first is a tracking task, in which participants control a blue dot on a screen with a joystick. The dot is surrounded by a large circle within which the dot moves randomly. Left unattended the dot will exit the circle in about 20 seconds. The participant can counteract the transgression by moving the joystick in the opposite direction. In the second task participants respond to the numbers 1, 2 and 3 by key-press, which appear in a never-ending, random sequence on the screen. Participants are instructed to handle both tasks, but know that the non-processed task will be temporally occluded until they press a trigger on the joystick to switch to the occluded task. Furthermore, participants receive rewards and punishments for their performance; for every number correctly entered they receive 20 points, but if the dot exits the circle they lose points. This punishment varied from losing all points, to losing half of the points or a fixed amount of 250 or 500 points. Results indicate that people adapt their tracking behavior dependent on the related reward function. Some participants risked more on the tracking task to get more points on the digit task, but overall they did not optimize their behavior and used a slightly conservative strategy of returning to the dot earlier than needed (Farmer, Janssen, Nguyen, & Brumby, 2017).

Applying DFT to this paradigm to understand individual differences in behavior and average task-switching behavior, would first necessitate an individual measure of risk-aversion/ risk-proneness. Such a measure could either be a general risk attitude scale or a domain-specific risk questionnaire (e.g. risk in financial decisions, risk in social decisions, Weber, Blais, & Betz, 2002) or a behavioral measure such as the well-established lottery task (Kahneman & Tversky, 1979) or the Balloon Analogue Risk Task (Lejuez et al., 2003). Let us assume individual risk in any of these measures was scaled from 0-100, with risk-averse participants scoring low and risk-prone participants scoring high on the scale. By having a measure of individual risk, we can predict choice probabilities and forecast that risk-prone individuals stay longer on the digit task while risk-averse individuals switch between tasks earlier and more often. Computational modelling techniques from DFT can then be used to predict choices and response times on the basis of these individual risk scores. The modelling procedure would use the individual scores to set individualized values for each DFT parameter (e.g. height of thresholds, anchor points for starting preference, etc.) and together, each DFT parameter value with the individual risk-scores, would then predict individual choice probabilities to switch and the expected time-on-task (see Wickens et al., 2015). We would hypothesize that people with higher risk scores have a lower threshold to decide for a risky choice, have a higher starting preference and more attention towards the risky option and spend more time on the risky task. For the dot-tracking paradigm (Janssen & Brumby, 2017), this would mean that a risk-prone person would have a higher starting preference towards the number task, would stay longer on this task trying to gain more points and would switch less often to control the dot. After finishing data collection in a dual-task, a data fitting approach would be applied comparing predicted and real data for each participant, always using the individual risk-preference data for one DFT parameter and keeping the remaining parameters constant. This comparison would be repeated for each DFT parameter to test which parameter fits the behavioral data best[[3]](#footnote-4). The description of switching behavior by mechanisms associated with DFT parameters, such as "starting preference", "threshold" or "attention weighing", would allow a closer understanding about the causes of behavior. The identification of the most qualified DFT parameter and individual measures that predict switching behavior, could reversely be used to manipulate reward functions of a task which in turn would prompt participants with a specific risk-proneness/-aversion tendency towards more optimal behavior. This would reduce individual differences in situations where we need a balanced behavior of risk among people. Finally, if individual differences of risk tendencies were known but tasks could not be easily adapted to them, further instructions or feedback about optimal behavior would optimize risk behavior in a given task. This understanding of “managing multitasking behavior”, leads to an adjustment of the interaction between task and person characteristics. This means we do not only accept peoples’ general tendency of risk behavior, but also a) accommodate tasks to risk tendencies and b) provide instructions and feedback in risky environments to help participants optimize their multitasking behavior.

In summary, we propose that the primary benefit of understanding multitasking as a choice is the prediction of thresholds for prioritization, which can be either prioritization for switching tasks or shifts in attention in dual-tasks. We argue that this can be achieved by exploring DFT parameters and by manipulating instructions and feedback or changes in task-reward functions. Taking multitasking research forward is a choice in itself. We argued that choosing a JDM perspective and using a one-choice metaphor for understanding multitasking behavior specifies a research program that allows for testing the added value of that choice.

**Compliance with Ethical Standards**

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*Figure 1*. Commonalities between JDM and Multitasking approaches with regards to cues, cognitive control, information processing, costs, outcomes and goals.

1. Information processing is understood as the ability to either carry out multiple operations in parallel, or to serially attend to one item at a time in succession (Schneider & Shiffrin, 1977; Snodgrass & Townsend, 1980). [↑](#footnote-ref-2)
2. In this paper we focussed on the transfer of JDM to multitasking, however it should be noted that we consider a bi-directional transfer as fruitful (e.g. Kahneman, 2011, for the transfer of attention and effort to JDM theories). [↑](#footnote-ref-3)
3. For a similar modelling approach of individual differences in choices using DFT parameters see Raab and Johnson (2004). [↑](#footnote-ref-4)