LUNDS UNIVERSITET

Department of Psychology

PSYK11

The Cost of Thinking

- Testing a Paradigm that Measures Mental Costs

Io Skogsmyr & **Agnes Wiberg**

Bachelor's Thesis Spring 2016

Supervisor: Åse Innes-Ker

Examinator: Sean Perrin

Abstract

Research on why we use a specific mode of thinking has long recognised the relevance of mental costs. The definition of this cost, however, has either been too abstract to be measured or focusing on metabolic costs, which currently is expensive and difficult to measure. In this experiment, we used a paradigm that measures the behavioural cost of three modes of thinking (rational reflection, emotional reflection and a comparison task) by the performance (reaction times) on a consecutive mental task (emotional and neutral Stroop). To get a measure of the participants' habitual way of thinking, we used a questionnaire covering two pedagogic constructs: separate and connected knowing (ATTLS). Reaction times were longest following rational reflective thought, while both emotional reflective thought and a comparison task led to shorter reaction times. These differences varied with task timing, so that the reaction times following the rational task became gradually shorter, while the emotional task led to increasing reaction times. Based on these results we suggest that rational and emotional reflection add differently to mental load and hence to switching between different modes of thought. A relationship between the individual performance on rational vs emotional processing and habitual way of thinking (measured by the ATTLS questionnaire) indicated ecological validity of the measures. Taken together, the paradigm shows promise as a tool for disentangling the interaction between, and cost of, different modes of thinking.

Keywords: task-retask, ways of knowing, CRT, cognitive dissonance, monitoring aversive affect

The Cost of Thinking – Testing a Paradigm that Measures Mental Cost

Cognitive control can be regarded as the result of a rational cost-benefit analysis, where emotions add valence to both benefits and costs (Botvinick, 2007). Even the regulation of the thought processes themselves has been regarded in this light (Westbrook & Braver, 2015). While cognitive functions are often discussed in terms of their relative costs, their specific value is seldom specified in comparable currencies (Christie & Schrater, 2015). Furthermore, these costs might differ depending on a person's preferred mode of thinking. As a general approach to understanding the world, some people use empathic reasoning while others are more prone to using logical skills (Belenky, Clinchy, Goldberger & Tarule, 1986). If regulation of thought processes is a result of a cost-benefit analysis, then these factors ought to vary depending on the favoured mode of assessing information (Zatorre, Fields & Johansen-Berg, 2012). In this study we aim to measure the cost of different modes of thinking, and to compare these costs to how people habitually integrate information.

Theoretical background

Imagine yourself as a student during a statistics exam. The calculations and formulas you memorised by heart in the comfort of your dorm room might unexpectedly seem unfairly impossible in the stressful environment of an exam. This is an example of how our emotional state impacts not only our feelings but also how we approach a problem (Muis et al., 2015). Hypothetically, what follows is that we will engage in different modes of thinking depending on the circumstances. Adjusting our modes of thinking is done subconsciously and is the result of an underlying cost-benefit evaluation (Botvinick, 2007). Though theories differ in just how they model this cost-benefit evaluation (Botvinick, 2007; Inzlicht, Bartholow & Hirsh, 2015; Okon-Singer, Hendler, Pessoa & Shackman, 2015; Westbrook & Braver, 2015), we conceive that at some basic level it should result from an interaction between neural networks. Like all mental functions, the underlying process of cost-benefit analyses is neural nodes summarising the input from both positive (action-related) and negative (inhibition-related) pathways. Logically, it is not a question of one independent mental process or area that makes the cost-benefit evaluation. Rather, the evaluation should be driven by pathways that represent information from gradually higher levels of information (e.g. Verbruggen, McLaren & Chambers, 2014). As a metaphor, much in the same way a computer program goes from 1/0 to the words you read on the screen.

The cost-benefit analysis approach to mental processing has been the interest of a wide range of psychological research fields, such as attitude studies, neuroeconomics, decision making, cognitive control and cognitive neuroscience (Dreisbach & Fischer, 2012; Verbruggen, McLaren & Chambers, 2014; Westbrook & Braver, 2015; Wittfoth, Schardt, Fahle & Herrmann, 2008). Even so, no consensus has been reached as to which factors are relevant for cost-benefit analyses, or even how they work (Christie & Schrater, 2015). In the following, we will combine information from this variety of fields in order to unravel which units of analysis are the most central when studying the cost of mental processing.

In neuroeconomics positive emotions (benefits) are increased by presenting participants with a monetary reward, which leads to a bias towards a specific behaviour (Westbrook & Braver, 2015). Participants will persevere on a boring/difficult task if this gives a higher reward than an easier task (Capa, Cleeremans, Bustin & Hansenne, 2011) which suggests that the balance between cost and benefit is altered by the resulting positive affect from an increased reward. In a study of attitude change of smokers, anti-smoking messages tailored to the specific needs of each smoker showed an increase in activation in medial prefrontal cortex that predicted future success to stop smoking (Izuma, 2013). What these studies suggest is that positive emotions add information to the decision-making process that regulates behaviour both related to the need for instant gratification as well as long-term goals.

Negative emotions, or aversive affect, add instead to the cost. Interestingly, there seem to be an overlap between the reaction to negative emotions and that of detecting conflicting, but neutral, information: both give rise to an aversive affect (Fritz & Dreisbach, 2013). As a consequence, Botvinick (2007) suggests that the area that registers both negative emotions and mismatching information, the anterior cingulate cortex (ACC), functions as an aversive state meter which promotes action by adding to the cost in the analysis of behaviour. The larger the cost, the higher the motivation to switch behaviour through cognitive control, and behaviours that have previously led to high aversive levels (or costs) will be avoided in the future (Kool & Botvinick, 2014). Thus, emotions not only steer towards gratifying goals, but also guide learning behaviour by acting as an aversive state meter that adds to the resolution of cognitive conflict.

In a similar vein of thought, Inzlicht et al. (2015) reason that emotion, as well as cognitive conflict, can be broken down into emotional primitives (e.g. core affect, facial expressions, physiological response, subjective experience, appraisal and attribution). These are evaluated during a monitoring phase in the anterior cingulate cortex (ACC), supplying information to the cost-benefit evaluation (Inzlicht et al., 2015). Some of the emotional primitives deal with the present (e.g. facial expressions and subjective experience) giving information of the current needs that must be taken care of. Others, such as appraisal and attribution, are more related to future goals. Hence the emotional primitives represent a mechanism that allows translation of long term costs and benefits into present reactions. This is necessary if the monitoring is to include a comparison between short and long term goals.

Modes of thinking

According to the dual-pathway principle (e.g. Evans & Stanovich, 2013; Kahneman, 2011; Stanovich & Toplak, 2012), both behaviour and its underlying thought processes are subject to a cost-benefit analysis; different cognitive functions have different costs and we will use a way of thinking that gives the best net outcome in a specific situation. Consider our example of the hard-working student. While (s)he might be tired from concentrating on writing a good essay, most students are likely to place a high value at the benefits of earning a degree. These benefits should motivate our student to make an effort. If, however, the student considers these benefits as trivial, (s)he might just write what comes of the top of his/her head, with little afterthought.

One example of the dual-pathway theories is that of Kahneman (2003) who argues that we have two kinds of thought systems, termed System 1 – which is fast and emotionally driven – and System 2, which is slow and logical. System 1 is based on relatively cheap processes, involving pathways that are used to a degree that allows for subconscious processing using heuristics. System 2, on the other hand, involves conscious thoughts that require processing of new ideas, which is costly and hence used infrequently (Kahneman, 2003). According to this theory, people tend to prefer using System 1 unless there is a specific reason to use the more costly System 2 (Kahneman, 2011). The reflective processes of System 2 supposedly exclude emotional information, a rationale that is arguably dated since complex decisions apparently can involve emotional information (Koelsch et al., 2015). If Botvinick's (2007) conception of an aversive state meter is accurate, the process by which we switch from System 1 to System 2 thinking is, in fact, partly driven by emotions. Furthermore, cost-benefit analyses monitor behaviour towards both present (Westbrook & Braver, 2015) and future goals (Capa, Cleeremans, Bustin & Hansenne, 2011) in terms of their emotional gratification. This suggests that in order to optimise benefits in the long term, optimal behaviour requires the capacity for emotional reflection in addition to rational reflection.

Further evidence in favour of the central role of emotions in regards to reflective thinking can be drawn from the field of educational psychology. Muis et al. (2015) propose a model in which different emotions cause different levels of processing in learning. Both positive and negative emotions can lead to deep processing strategies (comparable to System 2 processing) while affects such as anxiety, frustration and boredom cause shallow (System 1) processing. In terms of more advanced levels of knowledge acquisition, Belenky, Clinchy, Goldberger and Tarule (1986) propose that people differ in how they integrate new information in terms of the degree to which they use social/emotional thinking and logical thinking. Both connected (emotional) and separate (logical) knowers can be highly reflective, but use different approaches to learning; connected knowers are more prone to using empathic skills for understanding whereas separate knowers are more avid logicians (Belenky et al., 1986). Much used ways of thinking, as well as the neural pathways they engage, become more efficient due to brain plasticity (Zatorre, Fields & Johansen-Berg, 2012), which, in turn, increases working memory capacity (Okon-Singer, Hendler, Pessoa & Shackman, 2015; Vogel, McCollough & Machizawa, 2005). Therefore, we hypothesise that connected knowers have a lower cost of emotional reflection compared to separate knowers, and vice versa for the rational reflection.

If the use of cognitive functions is based on a cost-benefit analysis, a costly way of thinking is activated because it gives benefits that compensate for the increased cost (Kool, McGuire, Rosen & Botvinick, 2010). The higher the cost of a specific thought process, such as System 2, the greater the benefits need to be. Can we then surmise that rational thinking has a larger benefit than more emotive processes? To answer this question we need to start by measuring the relative cost of different modes of thinking.

Cost of cognition

Cost-benefit models of cognition differ in the way in which they conceptualise cost but share the problem of not being able to operationalise cost in a way that can be compared across modalities (Christie & Schrater, 2015). According to Kool and Botvinick (2014), relatively cheap cognitive processes have an intrinsic value. Furthermore, we make continuous labour/leisure decisions to balance rest and activity (Kool & Botvinick, 2014). Kurzban, Duckworth, Kable and Myers (2013) suggest that we have limited cognitive resources so that engaging in a specific task takes resources that could be used in other tasks, giving rise to an opportunity cost. Models such as these have been criticised for failing to specify what the limited resource is, treating cognition as separate from the underlying metabolic processes making thought possible (Christie & Schrater, 2015). Some theories focus more on the physiological limitations of mental processes, regarding cognition as costly in an energetic sense like in blood glucose usage (Gailliot et al., 2007). But such an approach is problematic since intense cognitive demand is estimated to increase metabolic costs by a mere 1% (Raichle & Mintun, 2006).

These theories fail to operationalise cost in a way that is comparable across modalities (Christie & Schrater, 2015). We suggest that a solution to this problem could be to use the same currency throughout, that is, to measure the cost of mental processes by the performance of a consecutive mental task. It is well established that there is a limit to the amount of information that can be processed simultaneously (e.g. Lavie, 2005; Lavie & Cox, 1997) but to our knowledge no paradigm has explored the concrete cost of mental load in itself. Like any psychological construct, mental cost has to be able to be operationalised in behaviour. The risk of confounding factors is lower in tasks involving relatively simple processing, such as the inhibition in a Stroop test (1935). In a Stroop task participants have to inhibit a well-practiced response in order to succeed in the task. The inhibition in turn, results from a monitoring activity involving the process of conflict identification (Botvinick, Braver, Barch, Carter & Cohen, 2001). Conflict identification gives rise to similar mental reactions irrespective if it arises from a simple task such as Stroop, or from complex modes of thinking such as emotional or rational reflection (Inzlicht, Bartholow & Hirsh, 2015; Schacht, Nigbur & Sommer, 2008). This overlap suggests that Stroop is a relevant measurement for the mental cost of reflection. In previous studies, Stroop items have been differentiated into, among others, emotional/neutral subcategories (Blanchette & Richards, 2013). Varying the levels of emotional content might give a more sensitive cost measurement, since we are interested in comparing the relative costs of emotional and rational reflection. Thus, in an exploratory effort we will use a Stroop paradigm with both emotional and neutral items as the operationalisation of cognitive cost.

Comparing Cognitive Costs

In this study we use a task-retask design, i.e. a paradigm that involves the measurement of the effect of one task on a second task (Vohs et al., 2008). The first task (hereafter called focus task) engages one of the cognitive functions we want to compare and the second task (hereafter called measurement task) measures reaction times as an indication of mental cost. The underlying assumption is that performance on the measurement task will depend on the resources available after depletion by the focus task (Vohs et al., 2008). To study mental processes that are relevant for different ways of knowing, we use tasks that engage either emotional or rational reflection, in this case the cognitive reflection test (CRT; Frederick, 2005) and a cognitive dissonance (Festinger, 1962) paradigm developed by de Vries et al. (2015). We surmise that emotional and rational reflection will have similar costs because they can involve reasoning of similar complexity (Koelsch et al., 2015). The baseline condition will induce cognitive consonance, i.e. a state of congruence between moral actions and moral attitudes that does not require conflict monitoring (de Vries et al., 2015).

A second assumption is that reaction times in Stroop tasks differ depending on the emotional content of the item presented, being either an emotional or a neutral word (Blanchette, Richards & Cross, 2007). By the use of a mixture of neutral and emotional Stroop as a measurement task, we can compare cost effects depending on emotional value of the focus tasks. This will allow us to study whether resources are used differently depending on the focus task being emotionally or rationally reflective.

Furthermore, we surmise that the habitual way in which the individual processes information allows them to perform some tasks more efficiently. Connected knowers have a greater aptitude for socio-emotional processing compared to separate knowers, who are more prone to logical-mathematical reasoning than connected knowers (Belenky et al., 1986). Taking knowledge about processing efficiency into account (e.g. Okon-Singer, Hendler, Pessoa & Shackman, 2015; Vogel, McCollough & Machizawa, 2005; Zatorre, Fields & Johansen-Berg, 2012), these differences in preferential modes of thinking should decrease the cognitive load, hence cost, of emotional reflection for connected knowers and rational reflection for separate knowers.

Hypotheses

Differences in Performance in Relation to Mental Task. Emotional and rational reflection will a) have similar costs because they involve reasoning of similar complexity (Koelsch et al., 2015). Having a high complexity further means that b) the rational reflection task will have a higher cost than the comparison task and c) that the emotional reflection task will have a higher cost than the comparison task.

Effects on Emotional vs Neutral Stroop Performance. There will be an additive cost effect for tasks that engage overlapping processes (Christie & Schrater, 2015). Hence we expect reaction times to be a) longer for emotional Stroop items following emotional reflection and b) longer for neutral Stroop reactions following rational reflection.

Relationships between Stroop Performance and Separate/Connected Knowing. Differences in how you habitually process information should have an effect on cost (Zatorre et al., 2012) so that a) connected knowers will have a lower mean reaction time in the Stroop task following the emotional reflection task and b) separate knowers will have a lower mean reaction time in the Stroop task following the rational reflection task.

Method

Participants

Thirty participants (17 female, 12 male, 1 other) were recruited by asking students from ten different courses at the department of psychology and the biology department at Lund University. The model of knowledge acquisition presented by Belenky et al. (1986) is based on university students, hence we searched for participants in an academic environment. Students were first presented with a summary of the aim and demand of the study, and then a list was passed in the classroom after we had left to avoid social pressure. The tutors collected the lists for us. In addition, we put out a description and asked for participation on the authors' personal Facebook pages. Age of participants ranged between 15-30 years (n = 19), 31-45 years (n = 3) and 45-60 years (n = 8).

Design

The design of this study was a mixed method design, consisting of an experimental procedure and a questionnaire. The experimental procedure was a task-retask design, meaning that each participant was tested several times on different independent measures paired with the same dependent measure (see Figure 1).

The paradigm was constructed of three sets of focus task-measurement task. While the focus tasks were balanced by Latin square, the measurement tasks kept their position. Not shown in Figure 1 are the practise items before each focus task and the first measurement task. The tasks were chosen from other studies where brain activation had been recorded by fMRI (Botvinick, 2007; Ruocco et al., 2014; de Vries et al., 2015). This gives an objective measure of which cognitive function, as well as the neural networks, the tasks activate.

The questionnaire was a translated version of the shortened Attitudes Toward Thinking and Learning Survey (ATTLS), a standardised measure of Belenky et al.'s (1986) concepts of connected and separate knowing (Galotti, Clinchy, Ainsworth, Lavin & Mansfield, 1999; see Appendix A). While the current design was mainly constructed with previously tested elements, the paradigm combination of both focus tasks and the mixed Stroop was designed to fit the research goals of this study.

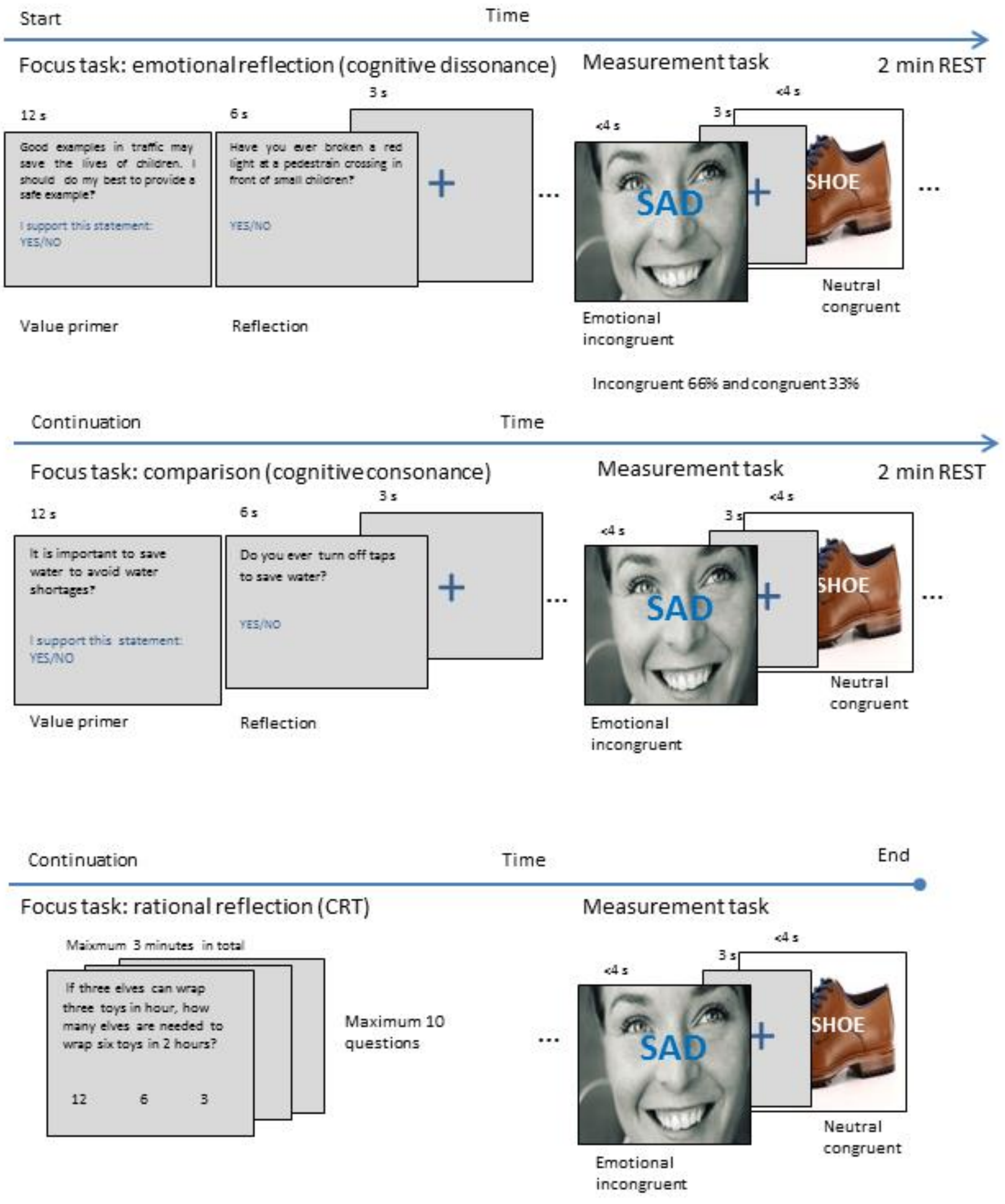

Figure 1. Illustration of the task-retask paradigm used in the study.

Materials

Translation Process. Although the translated items used in this study had not been previously validated, the authors were cautious of translation errors. In all translations, one of the authors translated the items to Swedish, thereafter the other changed the phrasing back to

English. We jointly checked for logical incongruities resulting from the translation process. In the translation of the CRT, we changed the units of measurement used in the original items to SI-standard (e.g. lbs to kg). In the ATTLS, content-based changes were mainly in terms of idiomatic expressions (see Appendix A).

The Rational Reflection Task. The items for the rational reflection task were derived and translated from Primi, Morsanyi, Chiesi, Donati, and Hamilton (2015) and Travers, Rolison and Feeney's (2016) extended versions of the original version of the cognitive reflection test (CRT) developed by Frederick (2005). The CRT was designed to activate a heuristic answer that needs to be suppressed if the correct answer should be given (Frederick, 2005) and reliably predicts the use of rational reflection (Toplak, West & Stanovich, 2011). In this study we used twelve translated items from Travers Rolison and Feeney (2016) and Primi et al. (2015); two were used as exercise examples and the other ten as the focus task. For each sample, the participants could choose between three possible answers. They consisted of problems such as this:

> An ice cream vendor sells 2/3 of her stock of ice creams on sunny days and 1/3 of her stock on cloudy days. Yesterday, it was a sunny day, and she sold 300 ice creams. Today is a cloudy day. How many can she expect to sell? (Primi et al., 2015)

The Emotional Reflection Task. The emotional reflection task consisted of a cognitive dissonance paradigm (de Vries, Byrne & Kehoe, 2015) which was used with permission after correspondence with Jan de Vries. Cognitive dissonance (Festinger, 1962) is an aversive feeling that arises when we are presented with conflicting information, such as when we act against our moral values. The 15 items of this task represented commonly occurring moral dilemmas that have been confirmed to induce cognitive dissonance (de Vries et al., 2015). Cognitive dissonance requires a higher-level regulation of emotions (Jarcho, Berkman & Lieberman, 2010) and uses the same conflict-monitoring processes as the measurement (Stroop) task (van Veen, Krug, Schooler & Carter, 2009; de Vries et al., 2015), making this task suitable for measuring the cost of emotional reflection. The items from de Vries et al. (2015) began with a value primer (statement) that the participant could either agree or disagree with. This was followed by a memory prompt in which the participant was asked to recollect an occasion in which (s)he acted in a way that conflicted with said value (see Figure 1).

The Comparison Task. The control condition consisted of a task, labelled "cognitive consonance" by de Vries et al. (2015), that was similar to the previous condition in all respects but that of inducing cognitive dissonance. The task started with the same kind of value primer as the dissonance task but the following memory prompt concerned a situation where the participant had behaved in accordance with the moral value. The cognitive consonance task is subjectively experienced as similar to cognitive dissonance, but does not induce conflict and hence allow for a shallower processing than the dissonance task and the cognitive reflection test (de Vries et al., 2015). This task was therefore judged as a suitable comparison (baseline) condition for the other tasks. Other than the content of the memory prompt, the cognitive consonance (comparison) task was constructed similarly to the emotional reflection (cognitive dissonance) task. As in the cognitive dissonance task, we used total of 15 items from de Vries et al. (2015) translated into Swedish.

Measurement Task. The measurement task consisted of a mixed Stroop paradigm that contained both emotional and neutral items with three levels of incongruence. Cost is hence operationalised as reaction time in this study. Conventional emotional Stroop paradigms compare reaction time for emotional words with that of unemotional words. However, Larsen, Mercer and Balota (2006) concluded that emotional words appear with a significantly lower frequency than non-emotional words. According to the word-frequency effect (e.g. Howes, 1957), words that occur more often in everyday language are more easily accessed than less common words. Thus, word frequency effects are taken into account by constructing items with emotional and neutral images instead of words.

Subdividing the incongruent condition into two levels of difficulty was based on the effect of picture-word interference (e.g. Lupker, 1979). Compared with coupling to categorically unrelated words, presenting two semantically related words together leads to slower reaction times and lower accuracy when participants are asked to name the words (Rosinski, 1977; Lupker, 1979). To get a measurement that included these differences, thus eventually picking up more nuances in cost, we used related (difficult) and non-related (easy) words for the incongruent items (Diaz et al., 2014; Vieth, McMahon & de Zubicaray 2014).

In the original Stroop the mismatch is between naming the colour of a font (e.g., red) and reading a colour word (e.g., green), representing mismatch between colour information from two interpretative pathways (MacLeod, 1991; Etkin, Egner, Peraza, Kandel & Hirsch, 2006). In a picture based Stroop it is possible to produce the same kind of processing; the pictorial information (e.g., a picture of a shoe) can represent the same category as the word information (e.g., sandal; van Maanen, van Rijn & Borst, 2009). This is not the case when an emotional Stroop is word based; then the visual information remains font colour, while the word (e.g., sad) belongs to a different category. Hence, picture based Stroop is more similar to the original Stroop than a word-based emotional Stroop (Etkin et al., 2006).

Emotional Stroop Items. Images for the emotional Stroop items were emotional faces from the Max-Planck Institute of Human Development (Ebner, Riediger & Lindenberger, 2010). The faces were younger, middle aged or older women and men and expressed five emotions; happiness, disgust, sadness, fear and anger. In its middle each face had an

emotional word superimposed. This word was either congruent or incongruent in relation to the expressed emotion on each face (see Figure 2).

Figure 2. Examples of emotional Stroop items that feature, from left to right: congruent, easy incongruent and ambiguous (difficult) incongruent faces.

The incongruent condition varied in difficulty on a two-level scale of easy to difficult. The difficult incongruent condition consisted of images superimposed with words that in combination with certain emotion words were judged to be ambiguous in regards to expressed emotion (e.g., sad-disgusted). This was done to vary the level of difficulty. In order to reduce the risk of psychological discomfort, the easy incongruent trials were mainly constructed with the faces expressing "happiness". Across all conditions, the congruent items were equally distributed across gender, age and emotion.

Neutral Stroop Items. In order to match the emotional faces on processing level, the neutral images consisted of pictures of neutral items, such as a shoe or book. A similar paradigm is used linguistics, i.e. picture word interference, though usually the pictures are drawings rather than photographs (e.g. Diaz et al., 2014). Here, photographs were used to make the neutral items in order to make them more similar to the emotional items. The neutral images depicted nouns that are equally common in general language (Vieth, McMahon & de Zubicaray, 2014). The images were retrieved from Google Images and were superimposed with either congruent or incongruent words. The incongruent trials were also divided into an easy and difficult condition. The subdivision into easy and difficult incongruence was based on whether the word was categorically related or not, following Vieth, McMahon and de

Zubicaray (2014) and Diaz et al. (2014). Examples of neutral Stroop items are depicted in Figure 3.

Figure 3. Examples of neutral Stroop items. Featuring, from left to right: congruent, difficult incongruent (categorically related), easy incongruent (categorically unrelated word).

Connected and Separate Knowing. Ways of knowing was measured with a translated version of the shortened Attitudes Towards Thinking and Learning Survey, or ATTLS (Galotti et al., 1999). The shortened ATTLS test was translated into Swedish and consisted of 20 questions tapping the tendency towards connected and separate knowing (see Appendix A). The survey included questions such as: “The most important part of my education has been learning to understand people who are very different from me.” (connected knowing) and “I find that I can strengthen my own position through arguing with someone who disagrees with me.”(separate knowing; Galotti et al., 1999). Our translated version of the ATTLS had not been tested for internal reliability prior to testing, but Galotti et al. (1999) had previously reported a Cronbach’s Alpha at .81 and .83 for connected and separate knowing respectively.

Procedure

After being informed about their formal rights, the participants were seated in front of a computer that was either located in the lab at the faculty of psychology or in the homes of the participants. The experiment was completed in E-Run, version 2.0, while the ATTLS was answered on an internet-based questionnaire through Google Forms after the experimental procedure was finished.

The task-retask paradigm consisted of three sets, each starting with a focus task which was followed by a measurement task (emotional/neutral Stroop; see Figure 1). All participants did all three focus tasks: emotional reflection (cognitive dissonance), rational reflection (CRT: the cognitive reflection task) and the comparison task (cognitive consonance). The order of the three focus tasks was balanced by the use of Latin Square. To follow the procedures used in the brain-imaging studies of the emotional reflection and comparison tasks (de Vries et al, 2015), the items appeared at a set pace. The value primer items were displayed for 12 seconds, the reflection items for 6 and the following fixation crosses for 3 seconds respectively (see Figure 1). The total time of these tasks was five minutes.

The rational reflection task was self-paced since a set pace could induce anxiety due to the difficulty of the task (e.g., Beilock & DeCaro, 2007), which could cause a heuristic approach to the problems. To induce a reflective approach to this task the participants were instructed to focus on trying to solve the problems rather than doing as many as possible. The items in the rational task shifted as participants answered a question by pushing keys on a computer. If the participant were not finished after three minutes they were asked to stop and the experimental leader moved the task forward to the measurement task. This was done since participants varied in their rate and the fastest finished this task just under three minutes. Hence we aimed to minimise the task time differences between individuals.

Before each focus task there were two practise items having the same kind of questions as the task and before the first measurement task there was four practise items. The second and third measurement tasks were only preceded by an instruction item saying that the measurement task was coming next. Between each set of tasks, participants took a 2 minute break, during which the experiment leaders initiated small talk in order to relax and distract participants from the procedure. After all three sets were done, the participants filled in the ATTLS questionnaire, where the sequence of questions was randomised each time. In all, the each session took about 45 minutes per participant including the debriefing session.

Ethics

Participants were informed of their formal rights and signed a printed out consent form, kept separately from other data. They were assigned a number as a subject ID, which was entered into the behavioural file and when answering the questionnaire. Hence the results were completely anonymous. After the experiment the participants were debriefed and asked to give their e-mail address if they wanted to read the report. Finally they were thanked for their participation. Using the Dissonance Measure (Elliot & Devine, 1994) de Vries et al. (2015) could not detect any residual negative affect after the cognitive dissonance task. Furthermore, since participants everyday face emotional expressions of different strength and valence, the risk of more permanent negative affect was judged as minimal.

Results

Rational reflection (CRT) generally led to a longer reaction time than emotional reflection (cognitive dissonance) and the comparison task (cognitive consonance) but this difference was dependent on both the order of the focus tasks and Stroop item type (Figures 4 and 5; Table 1).

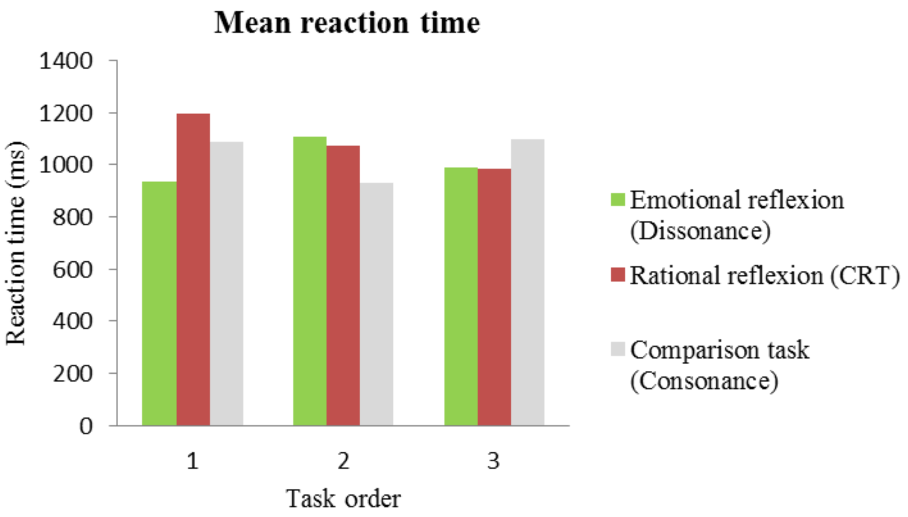

Figure 4. Simplified graph showing averages of all six item types (emotional; congruent/easy incongruent/difficult incongruent + neutral; congruent/easy incongruent/difficult).

The reaction times became gradually shorter with increased practise (order) when measurements followed the rational reflection task (Figure 4). Following the emotional reaction, however, they had a tendency to increase instead, while the comparison task

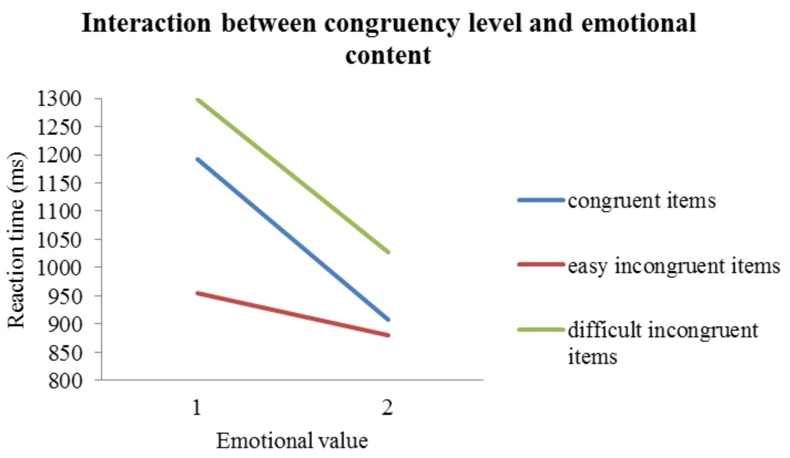

Figure 5. Reaction times for all levels of incongruence and both levels of emotion (i.e. emotional vs. neutral Stroop items).

generated a non-linear pattern (Figure 4). The three levels of congruency; congruent, easy incongruent and difficult congruence had a significant effect on reaction times (Table 1, Figure 5) in an unpredicted way: The difficult congruency – in accordance with normally found Stroop reactions – had longer reaction times than the congruent items. The easy congruency, on the other hand, turned out to have the shortest reaction times. This also affected the congruency by emotional interaction (Figure 5).

Table 1. *Results from an RM ANOVA showing an interaction effect between task, item type, and order on reaction time.*

		Within-subjects effects (3 levels of congruence)		
Sources of variation	*Df*	*F*	*P*	*Partial* η2
Task	2	2.63	.082	.089
Task x order	4	.99	.420	.068
Emotion	1	68.01	.001**	.72
Emotion x order	2	1.22	.313	.083
Congruence	2	52.86	.001**	.662
Congruence x order	4	1.32	.273	.089
Task x emotion	2	.075	.928	.003
Task x emotion x order	4	3.27	.018*	.195
Task x congruence	3.19[a]	2.05	.092	.071
Task x congruence x order	8	4.61	.001**	.232
Emotions x congruence	2	14.8	.001**	.354
Emotions x congruence x order	4	1.50	.215	.10
Task x emotions x congruence	4	1.04	.389	.037
Task x emotions x congruence x order	8	7.01	.001**	.342

[a] = df after Huyn-Feldt correction for sphericity.

Note: Task is either comparison task, emotional or rational reflection. Emotion denotes emotional/neutral Stroop and congruence is the three levels of congruence on the mixed Stroop. “Order” is a nominal value.

Since Stroop normally leads to shorter reaction times for congruent than for incongruent items (e.g., MacLeod, 1991), as well as for neutral in comparison the emotional items (Etkin et. al, 2006), we remade our analysis excluding the easy congruent task. This lead to similar interactions as the first analysis (compare Table 1 and 2), with the difference that we found a stronger effect of task and that the interaction between congruence and emotion disappeared.

Differences in Performance in Relation to Mental Task

Contrary to expectations, there was a difference between the reaction times following the emotional and rational reflection tasks: Reaction time following rational reflection (*M* = 1156.90 ms; *n* = 30; *SD* = 51.80) was longer than that following emotional reflection (*M* = 1062.64 ms; *n* = 30; *SD*= 49.71). Post hoc pairwise comparisons of main effects showed that this relationship was significant (mean difference = -94.25, *SD*: 39.34, *p* = .024). As hypothesised, however, reaction time following rational reflection was longer than that following the comparison task (*M* = 1097.74 ms; *n* = 30; *SD* = 49.08, mean difference: -59.16, *SD*: 26.67, *p* = .035). Lastly, not in accordance with our hypothesis, reaction time following emotional reflection was actually shorter than that following the comparison task (*M* = 1062.64 ms; *n* = 30; *SD*= 49.71, versus *M* = 1097.74 ms; *n*=30; *SD* = 49.08, mean difference: -35.10, SD: 38.78, *p* = .361).

Effects on Emotional vs Neutral Stroop Performance

For the analysis of emotional measurements in relation to task we excluded the easy incongruent items. Contrary to our predictions, there was no effect of task on the emotional and neutral items. Reaction times were longest for the emotional items after all three focus tasks (Figure 6a and b; Table 2). An interactive effect of task by order fluctuated however, so that reaction times to emotional items increased the later the task appeared in the paradigm (Figure 6a). The reverse was true for the reaction times following the rational reflection. The comparison task, again, had a peak when placed in the second position, a pattern which was shown in all analyses (Figure 4, 6*a* and *b*).

For the neutral items, reaction times were shortest in the third position for all different tasks (Figure 6 b and Table 2). Note that for the emotional reflection task, this was reverse to the order effect with the emotional items, where the third position had the longest reaction times.

Table 2 *Results from an RM ANOVA including difficult incongruent and congruent Stroop items - easy incongruent items excluded*

	Within-subjects effects (2 levels of congruence)			
Sources of variation	*Df*	*F*	*P*	*Partial* η2
Task	2	3.69	.031*	.120
Task x order	4	.99	.419	.069
Emotion	1	62.92	.001**	.70
Emotion x order	2	1.41	.262	.094
Congruence	1	26.41	.001**	.494
Congruence x order	2	.34	.715	.025
Task x emotions	2	.10	.903	.004
Task x emotions x order	4	4.77	.002**	.261
Task x congruence	1.87[a]	.23	.793	.273
Task x congruence x order	4	5.07	.002**	.273
Emotions x congruence	1	.09	.765	.003
Emotions x congruence x order	2	1.23	.308	.083
Task x emotions x congruence	2	1.68	.196	.059
Task x emotions x congruence x order	4	8.61	.001**	.390

[a] = df after Huyn-Feldt correction for sphericity. *Note: Follows the same coding pattern as Table 1.*

Relationships between Stroop performance and separate/connected knowing

Since reaction times varied between individuals, we used Cohen's *d* to get a measure of the difference between the reactions times after the emotional and neutral reflection tasks (Cohen, 1998). Cohen's *d* is a standardised measure for comparison between two factors. We calculated *d* as the difference between the average reaction times following emotional and

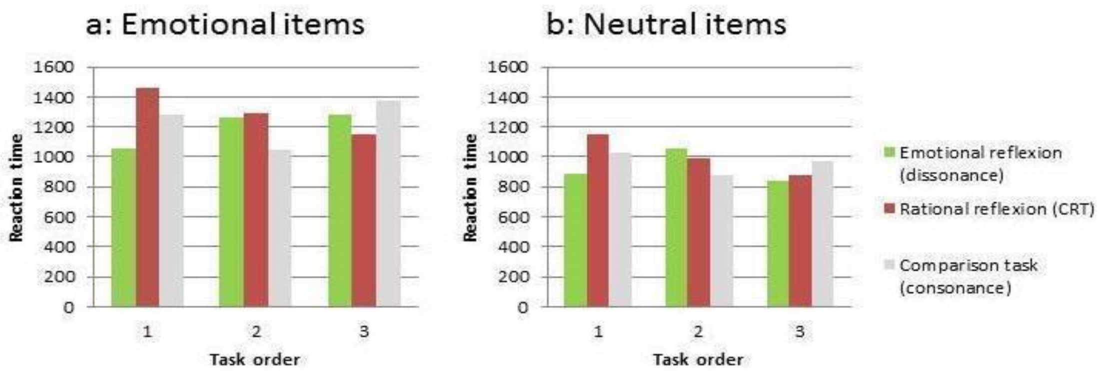

Figure 6 a and b. Reaction times for emotional and neutral Stroop items depending on focus task.

rational reflection respectively. These means were, in turn, based on individual means so that all individual values were included. The difference in reaction times was then divided by the pooled standard variation which was calculated from the standard variation in both sets of values (Cohen, 1998). Due to the influence of an outlier, we only used 29 out of 30 scores (*M* = .43, *SD* = .76, range = - .72 – 2.42).

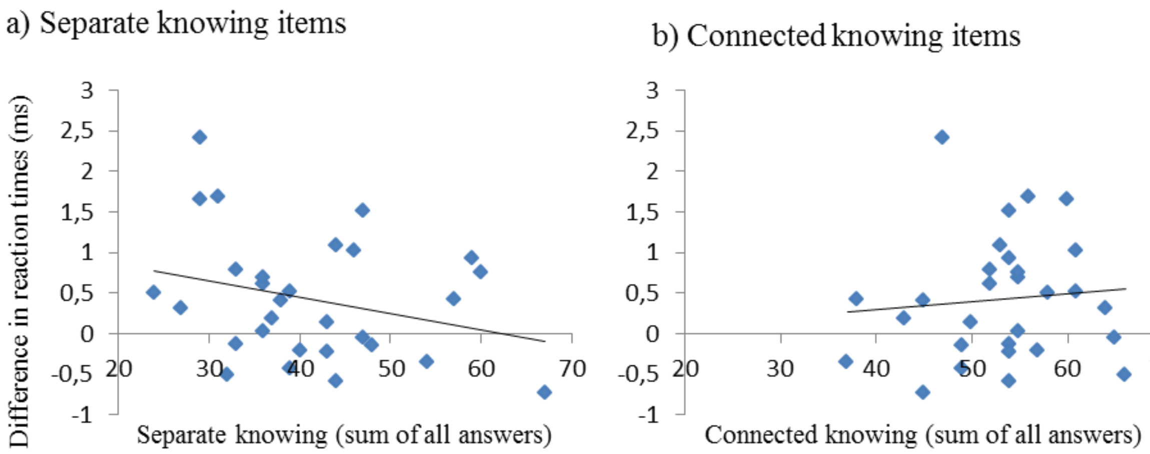

Figure 7 a and b. Relationship between ways of knowing and adjusted difference in reaction time following emotional and rational reflection (Cohens' *d*).

The score on the ATTLS was based on a 1-7 Likert scale that tapped both separate and connected knowing, giving each participant a total of two summed scores. Connected knowing had an internal consistency of α =. 79, while Cronbach's alpha reached α = .85 for separate knowing, which is similar to that of previous uses of the ATTLS (Galotti et al., 1999; Khine & Hayes, 2010).

The average participant had a slight preference for a more connected way of knowing. Generally, scores on the separate knowing scale (*M* = 53.26, *SD* = 7.12, range = 37-66) were higher than the average score on the separate knowing scale (*M* = 41.2, *SD* = 10.43, range = 24-67). There was less variance in the connected knowing scale (SD^2 = 50.62), than in the separate knowing scale (SD^2 = 108.86), which is opposite to previously reported uses of the ATTLS (Khine & Hayes 2010). With a sample of 128, Khine and Hayes (2010) reported variances of 69.22 and 55.50 for connected and separate knowing, respectively.

The relations between relative reaction time and ways of knowing partly supported our third hypothesis, i.e. that there would be a negative relationship to the separate knowing scale and a positive one to connected knowing. The difference in reaction time between the emotional and cognitive tasks increased with use of rational thinking (separate knowing,

Figure 7a), so that they reacted slower to emotional items compared to rational items. After correction for one outlier (*n* = 1) and order, separate knowing had an effect approaching significance (*r* = -.33, *p* = .084, see Figure 7a). Though the scale of connected knowing was positively related to the difference in reaction time, i.e. the reverse to the separate knowing scale, this was relationship was very weak (*r* = .079, p = .689, see Figure 7b).

Like previous uses of the ATTLS, we found a positive correlation between gender and ways of knowing. Women were more prone to connected knowing, and men to separate knowing, respectively. A post hoc bivariate regression showed that there was positive correlation between connected and separate knowing and gender (connected knowing: *r* = .387, *p* = .038; separate knowing: *r* = .383, *p* = .04).

Discussion

The task-retask design used in this study made it possible to directly compare the cost of different modes of thought. To our knowledge, this has not been successfully accomplished before. Overall, the rational reflection task was followed by longer reaction times than both the emotional reflection task and the comparison task. The interaction between order and cost of the task could imply that effects of learning and fatigue are dependent on whether the task is emotional or rational. The relationship between habitual mode of thought (ATTLS) and relative reaction time, indicate that the measurements have an ecological validity.

Differences in Performance in Relation to Mental Task

Equal Cost of Emotional and Rational reflection. In this study, the reaction times following the rational reflection task was longer than those following the emotional reflection task. While a high cost for rational reflection is on par with the theoretical assumptions made by Kahneman (2011), any firm conclusions about the relative cost of emotional and rational reflection should be treated with caution. Though we have compared rational and emotional thought processes, we do not know the relative intensity of the different tasks.

The rational reflection task is difficult; most participants will miss at least one question of the three used in the original version by Frederick (2005). A less difficult rational reflection task might give rise to a lower cost than the one used in this study. Furthermore, it is possible that the emotional reflection task was cheaper not because rational reflection is generally more expensive than emotional reflection, but because the emotional task induced a low intensity of cognitive dissonance (a low emotional load) (Imbir, 2015). The items were specifically chosen to represent commonly occurring moral dilemmas (de Vries et al., 2015).

De Vries et al. (2015) reported that these dilemmas did not leave any residual feelings of discomfort, which indicates that they generated merely a relatively low level of aversive affect.

There was an effect of repeating the measurements (order) so that the reactions times became shorter with increasing number of tasks after the rational reflections task and slightly longer after the emotional reflection task. The first example, where the reaction time became shorter could be the result of a learning effect (Davidson, Zacks & Williams, 2003). Several participants made the comment that they felt the measurement task became gradually easier. Even so, this was actually not true for reaction times after the emotional reflection task; here they became, if anything, longer which was most evident in the case with the emotional items of the measurement task. This might be due to effects of fatigue, but this does not explain why the more costly rational reflection did not show the same effect. Another answer could be that tiredness alone is not large enough to generate longer reaction times, but that in combination with emotional distress, such as caused by the cognitive dissonance in the emotional reflection task, the reaction slows down (Botvinick, 2007). If costs are additive, so that fatigue and emotional load act together, this might lead to switching to a less costly mode of thinking when a certain threshold is reached (Inzlicht et al., 2015, Kool et al., 2010). Such a process can produce the every-day equivalent of reacting emotionally – rather than rationally – when a demand is placed on you towards the end of a pressing day. Though very speculative, it is interesting to note that this is in accordance to the theory of an aversive state meter that registers emotional primitives, in this case tiredness and cognitive dissonance (Botvinick, 2007; Inzlicht et al. 2015).

Rational Reflection is More Costly than the Comparison Task. As predicted, reaction times after the rational reflection task was longer than those after the comparison task. The comparison task is designed so that it is easy to solve by the use of shallow processing (de Vries et al. 2014) and could thus be compared to the cognitively cheap system 1 thinking (Kahneman, 2011). It should be noted though, that reaction times following the comparison task in the third position was longer rather than shorter than those after the rational reflection task (see below).

Emotional Reflection is More Costly than the Comparison Task. Contrary to our hypothesis, there was no difference between the reaction times following emotional reflection task and the comparison task. Overall, the cost of the comparison task is hard to evaluate. The reaction times following this task were consistently shorter when the task was in the second position. One reason could be that the phrasing was “lost in translation”. Several participants pointed out that although they agreed with the first part of the value prompt, they did not agree to the conclusion. For example, even if they agreed to the value “Life is what you make of it. If you want it to be beautiful it will be beautiful.” they might not agree to “I should appreciate the beautiful things in life.”. Possibly this confusion was the result of the word “borde” which in Swedish has a different and more demanding value than “should”. While some participants found the task hard to answer, others said it was very pleasing, further complicating the picture.

Effects on Emotional vs Neutral Stroop Performance

Contrary to our expectations, the reaction times to the emotional items were consistently longer than those to the neutral items, instead of being the result of the kind of reflective task. If costs were only a direct effect of local metabolic use, as suggested by Gailliot et al. (2007), the more emotionally engaging task ought to have a higher emotional cost, since they presumably use the same resources (Vohs et al., 2008). Compared with the emotional reflection task, reaction time for both emotional and neutral items was higher following the rational reflection task. This could indicate that the reaction times are not dependent on local energetic demands, but the result of a more generalised cost evaluation (Botvinick, 2007). If so, a demanding task will leave less resources for any kind of subsequent mental task. The emotional reflection task, on the other hand, being less costly, leaves more resources for both emotional and rational processing in the measurement task.

The reason for the relatively high reaction time for emotional stimuli compared to neutral stimuli could be that we used faces for the emotional items (Müller-Bardorff et al., 2016; Pessoa, McKenna, Gutierrez & Ungerleider, 2002). While emotive faces are an everyday occurrence that participants should be able to process efficiently, faces are of fundamental interest to humans and engage both our emotions and attention (Etkin et al., 2006; Pessoa et al., 2002; Vuilleumier, Armony, Driver & Dolan, 2001). The increased reaction time could be the result of people spending more time on faces simply because they intuitively expect faces to carry crucial information – rather than indicating a processing cost (Frischen, Bayliss & Tipper, 2007; Kanwisher, McDermott & Chun, 1997). This does not seem plausible in our case; many participants commented on the difficulty of the emotional items compared to the neutral items. Had the processing time only reflected a positive affective state, this should not give rise to a feeling of difficulty (Higgins, 2006; Wang, Smith, & Delgado, 2016). Instead the higher cost might be due to the increased salience given to facial information making it worthwhile to spend more resources in this evaluation (Santos, Mier, Kirsch & Meyer-Lindenberg, 2011).

Relationships between Stroop Performance and Connected/Separate Knowing

It makes sense that your habitual way of processing information should impact what sort of task you excel at (Okon-Singer, Hendler, Pessoa & Shackman, 2015; Vogel, McCollough & Machizawa, 2005; Zatorre, Fields & Johansen-Berg, 2012). We assessed this effect by using the relative reaction time between the emotional and rational reflexion tasks. In accordance with our hypothesis, those who had a more logical-analytical thinking style had a longer relative reaction time to emotional processing, though larger sample sizes would be needed for a more convincing relationship. An indication that the sample size was too narrow – or small – was given by a lower variance compared to previous uses of the Attitudes Towards Thinking and Learning Survey (ATTLS: Khine & Hayes, 2010). Similarly to past observations, however, women were more prone to connected knowing while displayed a preference for separate knowing (Galotti et al., 1999). Furthermore participants in this study were chiefly from the faculty of psychology and biology. It would be interesting to see what would happen if we included students from other specializations such as civil engineering and social sciences, who might be expected to be more specialised in emotional or rational ways of knowing. By acquiring a more representative variability, it would be possible to get a more convincing picture of the predictive value of ways of knowing in terms of processing efficiency.

Limitations and future directions

The paradigm produced measurable differences in reaction times depending on tasks, which is interesting since the *n*-value was relatively low. Given that measurements of metabolic costs have showed an increase in glucose utilisation of only 1% (Raichle & Mintun, 2006), the effect sizes found in this study is comparatively high, which might be taken to indicate that the reaction times to mental tasks is more relevant and exact than glucose utilisation to elucidate differences between modes of thinking. In this study, we did not measure the intensity of mental effort, which made it hard to draw specific conclusions of the relative costs. One way to measure this intensity is to record the electromyographic activity in the corrugator supercilii muscle (cEMG). This muscle, which furrows the eyebrows, has been shown to react involuntarily to negative affect and fear (Lindström, Mattsson-Mårn, Golkar, & Olsson, 2013). Furthermore corrugator activity was prolonged in NoGo trials compared to

Go trials (Schacht, Nigbur and Sommer, 2009). Taken together, cEMG is a good indicator of monitoring intensity, whether it is generated by conflict or negative affect. Using cEMG would then make it possible not only to monitor the intensity generated by the different tasks but also to relate individual reactions with individual costs.

The reaction times to the difficult incongruent items were always longer than those to the congruent items, something which is commonly found in Stroop studies (MacLeod, 1991). However the reactions times to easy incongruent items were unexpected; not only were they shorter than either of the others in several circumstances but they also showed no effect of emotional value. In the easy neutral incongruent condition there was no clear semantic relationship between images and words (e.g., door-pen). Likewise, in the easy emotional condition, the relationship between expressed emotion and emotion word was clearly unrelated (e.g., happy-sad). In contrast, the word-image relationship in the difficult incongruent conditions was much closer, such as bicycle-wheel for a neutral item and sad-disgusted for an emotional item. In a colour – word Stroop, the relationship is between a lexical and visual stimulus of similar content (Etkin et al., 2006), hence resembling the difficult rather than the easy incongruent items. Care thus needs to be given to the items used in the Stroop, to ensure that they are dependable. One way to do this would be to simplify the emotional paradigm so that only happy and fearful faces are shown (Etkin et al., 2006). This would make the task more like a classic Stroop task.

The trial of the paradigm shows that though it would benefit from improvements, the paradigm provides opportunities for future studies on the mental cost of different ways of thinking. Testing both emotional and neutral items in the Stroop opens up for the possibility to evaluate effects on different kinds of processing. In all probability, the interaction effects found are rather an effect of the mechanisms themselves than the result of the method and should thus be embraced so that the paradigm is fine tuned to account for this complexity.

Conclusion

In conclusion, this study provides a method through which different kinds of thinking processes can be evaluated in terms of their costs. That rational and emotional reflective functions led to a variance in reaction times indicates that these functions might affect cost-benefit analyses in different ways, depending on cumulative effects. The inclusion of a measurement from the pedagogic literature extends the focus from the theoretical to situations that have a higher ecological validity. This is especially true in the university setting where modes of thought should be taken into account when constructing educational exercises for students: by including methods that engage both emotional and rational modes of thinking, not only will we reach out to students with different preferences but also provide the opportunity for all to practice different ways of thinking.

Using these results and paradigms as a stepping stone, it will be possible to develop further details of the precise trade-offs and interactions, answering questions such as: How does the emotional cost increase with emotional load? Is there a threshold where emotions change their effect from being merely informational to becoming directly executional? Can training of emotional monitoring, such as mindfulness meditation, affect cost (and if so, does it affect the negative valence during monitoring or the control function)? What kinds of recuperations are effective to restore optimal cognitive control and help people to overcome negative effects of emotional stress? Through its applications, the studied paradigm thus has the possibility to make a major contribution to the well-being and long-term benefits of people and societies in an ever more demanding and stressful environment.

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Appendix A.

Table 1 *Translated items for the Attitudes Towards Thinking and Learning Survey (Galotti, Clinchy, Ainsworth, Lavin, Mansfield, 1999)*

Connected Knowing Items
När jag träffar på någon som verkar ha annorlunda åsikter än jag anstränger jag mig för att leva mig in i deras situation för att förstå varifrån deras åsikter kommer.
Jag kan genom empati nå insikt om åsikter som skiljer sig från mina.
När jag diskuterar kontroversiella ämnen brukar jag leva mig in i andras situation, för att jag ska förstå varför de tänker som de gör
Det är troligare att jag skulle försöka förstå en annan persons åsikt än att jag skulle utvärdera den.
Jag försöker hålla med personer istället för att tala emot dem
Jag får ökad självförståelse när jag får prata med flera olika sorters människor.
Jag är alltid intresserad av att förstå varför personer säger och tror på det de gör.
Jag tycker om att höra åsikter från människor med annorlunda bakgrund än min – det hjälper mig
Den viktigaste delen i min utbildning har varit att lära mig förstå människor som är väldigt annorlunda jämfört med mig själv.
Jag gillar att få veta mer om andra människors liv, vilka erfarenheter som lett till att de känner som de gör.

Separate Knowing Items
Jag gillar att spela ”devil’s advocate”, att argumentera tvärtemot det en person säger.
Det är viktigt för mig att genomgående vara så objektiv som möjligt när jag analyserar något.
När jag lyssnar till andra människors åsikter försöker jag förhålla mig kritiskt.
Jag anser att jag kan stärka min egen ställning i olika frågor genom att argumentera mot människor som inte håller med mig.
Man skulle kunna definiera mitt sätt att analysera saker som att ”sätta dem på prov”, eftersom jag är väldigt noggrann när jag överväger alla bevis.

När jag läser en bok hamnar jag ofta i ett slags debatt med författaren där jag försöker hitta logiska fel i texten.

Jag använder särskilda kriterier när jag utvärderar ett argument.

Jag försöker peka ut svagheter i andra personers sätt att tänka för att hjälpa dem klargöra sina argument.

När jag löser problem föredrar jag att använda mig av logik och resonerande istället för att blanda in mina egna känslor.

Jag lägger ned tid på att komma på vad som är ”fel” med saker och ting, t.ex. genom att leta efter svagheter i argumenten i en text.