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Differences in the distribution of reaction times of single and double decisions and their relations to working memory

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Abstract

Aging is an important factor for decreased performance on single reaction time tasks. However, single decisions in reaction time tasks might not contain the most predictive power of everyday cognitive functioning in people. This thesis aims to achieve a description of behavior, like chained decisions, that better resembles everyday functioning. With this purpose in mind, we investigated the differences in the distribution of reaction time of single and double decisions and their relation to WM. This was done by using a clinical task that measured the span of WM and by using reaction time tasks that consisted of color and contrast judgment tasks. Three levels were used in the reaction time tasks, single decisions, double independent decisions, and double dependent decisions. These tasks were used to get the drift rate, boundary separation, and non-decision time of reaction times of the EZ-diffusion model. There was an effect on all three parameters on single decision tasks compared to the double decision tasks. However, no effect was found between the double independent decisions and the double dependent decisions. Also, the link between the cost of making a double decision and the span of WM was non-significant although in the expected direction. Follow-up research is recommended to test these effects with a higher statistical power.

Keywords: working memory | EZ-diffusion model | single decisions | double independent decisions | double dependent decisions

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Due to the growing population with longer life expectancy, the number of people with dementia is expected to double between 2015 and 2040 (Staat van Volksgezondheid en Zorg, 2018). Dementia has a disruptive effect on the life of the person and the lives of the people close to the person. Therefore the impact of dementia on society and healthcare is significant (Rijksinstituut voor Volksgezondheid en Milieu, 2018; Tabue-Teguo, 2017; Baumgarten et al., 1992). An early diagnosis increases the likelihood that treatment will help stabilize or slow down the degenerative process of dementia (Rasmussen et al., 2019). To realize early diagnosis, it is crucial to investigate cognitive functioning (Jongstra, et al., 2017).

When looking at cognitive functioning, deficits in working memory (WM) are a significant factor in detecting dementia (Huntley et al., 2009; Morris et al., 1988). WM can be defined as the system for the temporary maintenance and manipulation of information that is necessary for the performance of complex cognitive activities such as decision-making, comprehension, learning, and reasoning. (Baddeley, 1992; Oberauer et al., 2008). Tasks that measure WM performance, are taken reaction times (RTs) into account (Schmiedek et al., 2007). The reaction time is the time that is needed to answer to a physical stimulation (Laming, 1968). Ratcliff et al. (2010) showed that RTs slowed considerably when people get older. RTs are extremely variable, even when repeating a decision on the same stimulus and vary in an unexpected way compared to usual random variables such as the height of individuals (Noorani & Carpenter, 2016). This singular variability, the shape or density of the distribution of multiple RTs by the same participant, likely gives us information on the psychological processes underlying the execution of a particular RT task (Schmiedek et al., 2007). To decompose RTs into a hypothesized set of underlying processes, the EZ-diffusion model can be applied (Wagenmakers et al., 2007). The EZ-diffusion model is a model for two-choice response time tasks that takes the mean response time, variance of response time, and response accuracy of a single participant as inputs. The model transforms these data via three equations to produce unique values for the quality of information processing (drift rate), response conservativeness (boundary separation), and non-decision time (Wagenmakers et al., 2007). First, the quality of information processing is meant to represent the average amount of evidence accumulated per unit time, *i.e.* speed of processing. Furthermore, it is an index of task difficulty when comparing the same participant across different conditions or participant ability when comparing different participants. Second, response conservativeness is meant to represent the level of caution. When the response time is longer, it results in fewer errors. Long RTs can come from a low drift rate or high thresholds. What decreases the likelihood of hitting the incorrect response is the increase in required evidence, which in parallel also increases the length of the RTs. Therefore, response conservativeness implements the speed-accuracy trade-off (Wagenmakers et al., 2007; Forstmann et al., 2016). This means that the accuracy of the decision depends on which accumulator crosses which boundary, and the speed is given by the time it takes (Stafford et al., 2020). Third, by the non-decision time, it is supposed to measure the time for peripheral processes like encoding a stimulus, transforming the stimulus representation into a decision-related representation, and executing a response (Forstmann et al., 2016). The transformation of observed data in terms of unobserved variables addresses the speed-accuracy trade-off and allows an unambiguous quantification of performance differences in single reaction time tasks (Wagenmakers et al., 2007). RTs alone cannot discriminate whether a participant has slow RTs because of impaired speed of processing or whether it is due to high decision thresholds. The EZ-diffusion model, on the other hand, is a more sensitive measure because it estimates with both speed and accuracy. Furthermore, it takes into account both the mean response time and the distribution of response times for correct and error responses (Stafford et al., 2020). With regard to aging, older people have slower RTs because they set wider boundaries and their non-decision component is longer. Nevertheless, accuracy decreased only minimally because drift rate decreased only minimally (Ratcliff et al., 2010).

However, single decisions might not contain the most predictive power of everyday cognitive functioning in people. In daily life, decision-making situations are split into multiple sequential decisions (*e.g.* is the traffic light orange or green, should I break or finish crossing?). These multiple sequential decisions can be dependent or independent of each other. Pashler (1984), and Sigman & Dehaene (2006), showed that people do not have the ability to process multiple independent stimuli when they are presented closely in time. One of the explanations is that it is due to the psychological refractory period (PRP). The PRP effect is the slowing that almost invariably occurs when a person tries to perform two speeded tasks at approximately the same time (Pashler, 1994). The effect suggests that it comes through a bottleneck mechanism. In other words, this means that when a process occurs in one task, the process cannot occur in any other task simultaneously. Processing one task temporarily prevents the execution of crucial steps of a temporally overlapping task (Pashler, 1994; Fan et al. 2012). When it comes to investigating the cost that is associated with tasks where the performance of the second task depends on the outcome of the first task, much less is known about it. Fan et al. (2012) showed that when tasks depend on each other, RTs are slower and more variable. This can be explained by the fact that two tasks that are dependent on each other require more cognitive resources than the same two tasks that do not require transfer. Serial chaining consumes central processing resources and requires persistent conscious control (Sackur & Dehaene, 2009; Fan et al., 2012).

So, it can be said that when multiple sequential decisions are independent of each other they have a low WM load, unlike serial chaining which has a high WM load (Meiran, & Shahar, 2018).

To explore if the distribution of several RTs raised from sequential decisions might be a better predictor of everyday cognitive functioning, we build an experimental design in which participants will complete simple or sequentially chained decisions and compare the distributional properties of those tasks to the outcome of a working memory test. With this study, we hope that further research can be done to increase insight into cognitive functioning. In this thesis, no difference is expected on drift rate, boundary separation, and non-decision time between the single decisions and the double independent decisions (whether the task is on color or contrast). Furthermore, a higher threshold is expected in the first decision (color task) on boundary separation on the double dependent decisions compared to the double independent decisions. Moreover, a lower drift rate is expected in the second decision (contrast task) on the double dependent decisions compared to the double independent decisions. In addition to that, a longer non-decision time is expected in the second decision (contrast task) on the double dependent decisions compared to the double independent decisions. Finally, a linear relationship between the span of WM and the difference on drift rate on the double dependent decisions and the single decisions in the contrast task is expected. This experiment will be conducted in a non-clinical population. The experiment consists of four tasks, simple response tasks, and double response tasks. These tasks are then compared to a task that measures working memory capacity that is regularly used in clinical assessments.

Method

Participants

The experiment was conducted by using a convenience sample according to the standard University procedures, social media platforms, and word-of-mouth contact. The sample of current research consisted of 20 healthy participants. The requirements for participation in the present study are normal or corrected visual acuity, no color blindness, and an age of more than 18 years. The experiment was approved by the Faculty of Ethics Review Board of the Faculty of Social Sciences (22-1526). Before the start of the experiment, all participants signed an informed consent form following the Declaration of Helsinki and Utrecht University guidelines. Students of the University of Utrecht were compensated for their participation by receiving course credits.

Apparatus

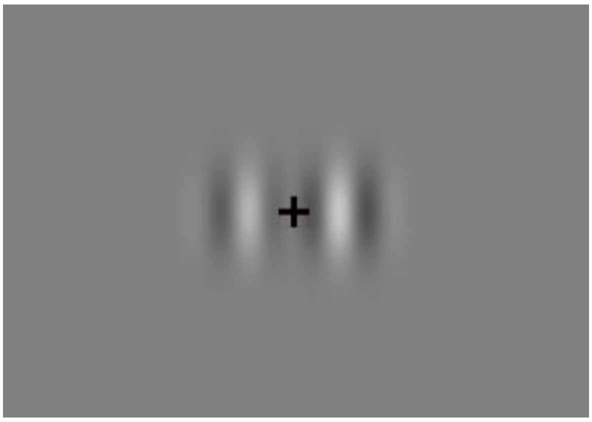
Participants have seated in a comfortable chair about 100 cm away from a 19-inch Eizo FlexScan S1934H monitor that had a refresh rate of 60 HZ or a 14-inch Acer Swift 3 SF314-54 screen that also had a refresh rate of 60 HZ. The current experiment, which consisted of several reaction time tasks, was programmed in Python version 3.8.10 and was run by PsychoPy-2022.1.3. Data processing was performed in Excel version 2205 and JASP 0.16.2 for statistical analyses. Responses were given by pressing the arrow keys on a separate keyboard that were recommended in the instructions.

Stimuli

Stimulus presentation was controlled by the software PsychoPy (Peirce, 2007). Each trial consists of one fixation cross, one square with varying colors, and two sinusoidal gratings with varying contrast. An overview of a trial is shown in Figure 1. The square of color had an opacity of .03. With 0 being transparent, and 1 fully visible. The participant task was to indicate whether the square was green or red with the corresponding button press. The two sinusoidal gratings had a contrast difference between left and right of 0.14. With again 0 being transparent, and 1 fully visible. The participant task was to indicate which grating had a higher- or lower-contrast with the corresponding arrow key. At each trial, the stimuli color was randomly green or red. This randomization was also independently applied to the two sinusoidal gratings.

Figure 1

An overview of a trial



Note. Trial with one fixation cross; two sinusoidal gratings with higher contrast on the right; one red square

Experiment

The experiment consisted of two different tasks. The first task was a reaction time task. This task consisted of four modalities. Each modality was presented in 200 trials. Two modalities were single RTs, which consisted of color or contrast judgment tasks. The other two modalities consisted of double RTs. One was a dependent task and the other was an independent task. During the dependent task, the instructions changed with the color, when it was green participants had to respond to the most contrasted and if it was red, they had to respond to the least contrasted. During the independent task, the square of color and the sinusoidal gratings of contrast were not related to each other.

The second task was the Digit Span Task (Backwards), a widely used clinical task to measure WM (De Tollis et al., 2021). At this task, the examiner said a sequence of digits, and then the participant must immediately repeat the numbers in reverse order. If the participant responded correctly in one out of the two trials, the next trial presented a longer sequence. Thus, the task ended when participants responded incorrectly on two occasions at a span length. The participant's span was the longest number of sequential digits that can accurately be remembered. (Wechsler, 2012; Kramer et al., 2003). The reliability and validity of the Digit Span Task (Backwards) have been tested in numerous studies (Reynolds, 1997; Conway et al., 2005), with results showing it is a reliable assessment tool to evaluate WM.

Procedure

Participants performed the experiment in a small lab space at Utrecht university or in a small office in Rijssen (Overijssel) with no distractions from the outside. It started with an introduction to the subject and the aim of the research. It also emphasized the anonymity of the participants, the confidentiality of the data, and voluntary participation. After this, the participants were asked to sign an informed consent form. Then some questions about age and gender were filled in. Before the start, the task was briefly explained.

The current experiment started with 30 practice trials to get the participants familiar with the experiment. In these practice trials, the participants got familiar with all four modalities. This was followed by the actual task. The four modalities were broken up into blocks of 100 trials. After each block, the participant received feedback on the monitor about how fast and accurately they responded. This was followed by instructions for the next block which provided information of the modality. A self-initiated break was possible after each of the 100 trials and at the end of the task. The researcher stayed in the room to answer any questions. After this, participants were asked to participate in the Digit Span Task (Backwards).

Hereby, the researcher said a given number of digits, and the participant had to repeat it backwards. After completing two practice trials, the actual task started. The task ended when the participant got two trials incorrect for one given length of numbers. Both tasks were followed by a short debriefing. The total length of the experiment was about 60 minutes.

Data-analysis

After the data was acquired through Excel version 2205 the program JASP 0.16.2 was used to further analyze the data. Before analyzing the data one of the 21 participants was not included in the data analysis, because of missing data on the reaction time task. Participants had to finish both tasks for their data to be included. The first task measured the RTs of the participants. In the single modalities, trials with RTs less than 200 ms and greater than 2000 ms were excluded. For double modalities applied, trials with RTs below 200 ms and above 4000 ms were excluded. Using JASP the RT means, RT variance, and the proportion of correct responses was calculated. We assumed that the assumptions for an EZ-diffusion model, such as the shape of the RT distributions, whether the starting point is unbiased, and the relative speed of error responses were fulfilled. The RT means, RT variance, and the proportion of correct responses were converted through the EZ-diffusion model. This conversion was done by a JavaScript program that computes the parameter values (drift rate, boundary separation, and non-decision time) for the EZ-diffusion model (Wagenmaker et al. 2007). The reaction time task consisted of two tasks (color or contrast), and three levels single, double independent, and double dependent, in which each level consisted of drift rate, boundary separation, and non-decision time. To look at whether there was a difference between the tasks (color or contrast) and the three levels containing the three parameters, six one-way repeated measures ANOVAs were used. For an overview see Table 1. Before conducting a one-way repeated measures ANOVA the assumption of sphericity was checked (Field, 2018). For each repeated measures ANOVA, the *F*-test was reported, which indicates whether the model provided a better fit to the data than a model that contained no independent variables. Furthermore, the significance was reported through the *p*-value. In addition, using post hoc comparisons Cohen’s *d* was reported, which expresses the difference between two means in standard deviation units. Moreover, the *t*-statistic was reported, to see whether the difference between the means was significantly different from zero (Field, 2018). The threshold for significance of a repeated measures ANOVA was set at $\alpha = .05$. Also, the mean and the standard deviation of the mean RT and accuracy for all participants were tested for both tasks and their three levels.

Table 1

Overview of the tasks and the three levels containing the three parameters

	Color			Contrast		
Single	Drift rate	Boundary separation	Non-decision time	Drift rate	Boundary separation	Non-decision time
Double independent	Drift rate	Boundary separation	Non-decision time	Drift rate	Boundary separation	Non-decision time
Double dependent	Drift rate	Boundary separation	Non-decision time	Drift rate	Boundary separation	Non-decision time

Note. Overview of the tasks (color and contrast) and the three levels single, double independent, and double dependent, in which each level consisted of drift rate, boundary separation, and non-decision time

The second task, the Digit Span Task (Backwards), measured the maximum span of WM of a participant. To know whether there was a linear relationship between WM and the difference on drift rate on the independent and dependent contrast task, a simple linear regression was conducted. The assumptions of simple linear regression, such as linearity, independency of the residuals, multicollinearity, homoscedasticity, and normally distributed residuals, were tested before performing the data analysis (Field, 2018). For the simple linear regression analysis, the correlation between both variables, R, and the variance of the dependent variable, which could be explained by the independent variable, R^2 were reported. Furthermore, the F-test was reported. In addition, the strength and significance of the effect of the independent variable on the dependent variable were reported through parameter estimate b and p-value (Field, 2018). Again, the threshold for significance was set at $\alpha = .05$.

Results

First, the mean (M) and the standard deviation (SD) of the mean RT and accuracy for all participants were tested for all six modalities, as shown in Table 2.

Table 2

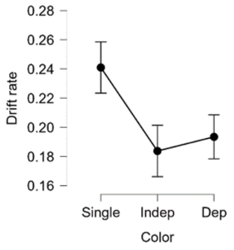
Distribution of the M and the SD of the mean and accuracy for all six modalities of the participants

	M of mean RT	*SD*	*M* of accuracies	*SD*
Color	0.772	0.133	0.969	0.031
Contrast	0.646	0.130	0.979	0.021
Independent color	1.153	0.223	0.970	0.030
Independent contrast	1.397	0.269	0.976	0.022
Dependent color	1.153	0.246	0.975	0.035
Dependent contrast	1.422	0.271	0.961	0.028

Furthermore, six repeated measures one-way ANOVAs were used to test whether there was a difference between the task (color or contrast) and the three levels, single, double independent, and double dependent, in which each level consisted of drift rate, boundary separation, and non-decision time. The assumption of sphericity was tested and fulfilled in JASP for all six repeated measures ANOVAs. In the results there was a significant effect of the conditions in the color task on drift rate *F*(2,36) = 14.70, *p* < .001. Post hoc comparisons revealed that this was due to a significantly higher drift rate to the single reaction time task compared to the independent double reaction time task (*t*(36) = 5.06, *p* < .001, *d* = 1.20), and also compared to the dependent double reaction time task (*t*(36) = 4.21, *p* < .001, *d* = 1.00). There was no significant effect found between the independent and dependent double reaction time task (*t*(36) = -.86, *p* = .397, *d* = -.20). An overview of the post hoc comparisons is shown in Figure 2.

Figure 2

A line chart of drift rate for the single, independent, and dependent conditions on factor color

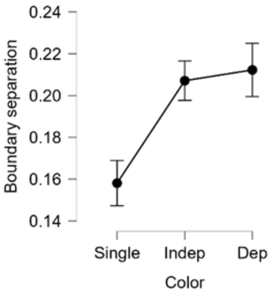


Note. The drift rate for the single condition was significantly higher than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

In the second repeated measure ANOVA, there was a significant effect of the conditions in the color task on boundary separation *F*(2,36) = 32.04, *p* < .001. Post hoc comparisons revealed that this was due to significantly lower thresholds for the single reaction time task compared to the independent double reaction time task (*t*(36) = -6.56, *p* < .001, *d* = -1.43), and also compared to the dependent double reaction time task (*t*(36) = -7.25, *p* < .001, *d* = -1.57). There was no significant effect found between the independent and dependent double reaction time task (*t*(36) = -0.69, *p* = .494, *d* = -.15). An overview of the post hoc comparisons is shown in Figure 3.

Figure 3

A line chart of boundary separation for the single, independent, and dependent conditions on factor color

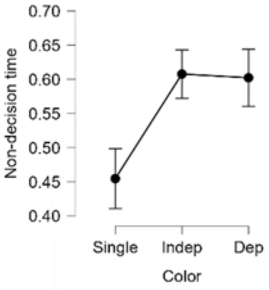


Note. The drift rate for the single condition was significantly lower than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

Third, there was a significant effect of the conditions in the color task on non-decision time *F*(2,36) = 20.30, *p* < .001. Post hoc comparisons revealed that this was due to significantly shorter non-decision time for the single reaction time task compared to the independent double reaction time task (*t*(36) = -5.62, *p* < .001, *d* = -1.33), and also compared to the dependent double reaction time task (*t*(36) = -5.42, *p* < .001, *d* = -1.29). There was no significant effect found between the independent and dependent double reaction time task (*t*(36) = .20, *p* = .844, *d* = .05). An overview of the post hoc comparisons is shown in Figure 4.

Figure 4

A line chart of non-decision time for the single, independent, and dependent condition on factor color

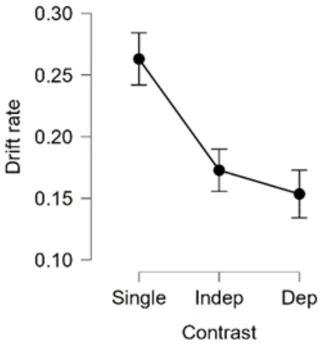


Note. The non-decision time for the single condition was significantly shorter than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

In the fourth repeated measure ANOVA, there was a significant effect of the conditions in the contrast task on drift rate $F(2,30) = 41.71$, $p < .001$. Post hoc comparisons revealed that this was due to a significantly higher drift rate to the single reaction time task compared to the independent double reaction time task ($t(30) = 7.05$, $p < .001$, $d = 2.09$), and also compared to the dependent double reaction time task ($t(30) = 8.55$, $p < .001$, $d = 2.54$). There was no significant effect found between the independent and dependent double reaction time task ($t(30) = 1.50$, $p = .143$, $d = .45$). An overview of the post hoc comparisons is shown in Figure 5.

Figure 5

A line chart of drift rate for the single, independent, and dependent conditions on factor contrast

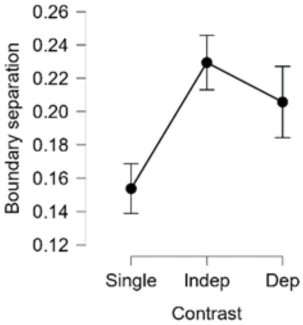


Note. The drift rate for the single condition was significantly higher than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

Fifth, a significant effect was found of the conditions in the contrast task on boundary separation *F*(2,30) = 21.51, *p* < .001. Post hoc comparisons revealed that this was due to a significantly lower threshold for the single reaction time task compared to the independent double reaction time task (*t*(30) = -6.41, *p* < .001, *d* = -1,76), and also compared to the dependent double reaction time task (*t*(30) = -4.40, *p* < .001, *d* = -1,21). There was no significant effect found between the independent and dependent double reaction time task (*t*(30) = 2.01, *p* = .054, *d* = .55). An overview of the post hoc comparisons is shown in Figure 6.

Figure 6

A line chart of boundary separation for the single, independent, and dependent conditions on factor contrast

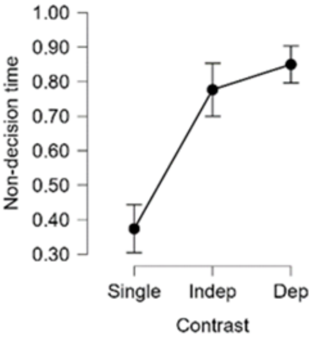


Note. The boundary separation for the single condition was significantly higher than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

In the sixth repeated measure ANOVA, there was a significant effect of the conditions in the contrast task on non-decision time *F*(2,30) = 65.91, *p* < .001. Post hoc comparisons revealed that this was due to significantly shorter non-decision time for the single reaction time task compared to the independent double reaction time task (*t*(30) = -9.02, *p* < .001, *d* = -2,56), and also compared to the dependent double reaction time task (*t*(30) = -10.66, *p* < .001, *d* = -3.03). There was no significant effect found between independent and dependent tasks (*t*(30) = -0.47, *p* = .111, *d* = -.47). An overview of the post hoc comparisons is shown in Figure 7.

Figure 7

A line chart of non-decision time for the single, independent, and dependent condition on factor contrast

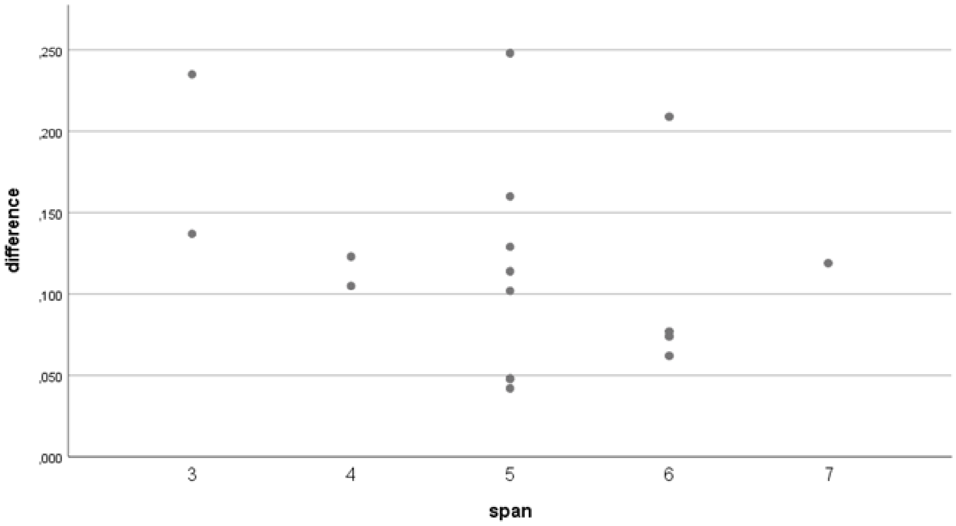


Note. The non-decision time for the single condition was significantly shorter than for the independent and dependent conditions. There was no significant effect between the independent and dependent condition

Because there was no effect found between the independent and the dependent double reaction time task. There was no reason to expect a linear relationship between WM and the difference on drift rate on the independent and dependent contrast task. Because a significant effect was found on drift rate between the single reaction time task and the dependent double reaction time task, it was now expected that there is a significant linear relationship between WM and the difference on drift rate on the dependent and single task contrast task. A simple linear regression analysis was used to test this relationship. The data of two of the 20 participants were not included in the data analysis, because of missing data of drift rate on the single decision task. Using the data from 18 remaining participants, all assumptions, such as linearity, independency of the residuals, multicollinearity, homoscedasticity, and normally distributed residuals were tested and fulfilled. For more details see the Appendix. In the results there did not appear to be a significant relationship between WM, and the difference on drift rate on the dependent and single task contrast task $F(1,16) = 1.42$, $p = .250$. However, the association was negative as expected ($R = .286$, $R^2 = .082$, $b = -.017$). For an overview see Figure 8.

Figure 8

Plot of WM span and the difference on drift rate



Note. There did not appear to be a significant relationship between WM, and the difference on drift rate on the dependent and single task contrast task

Discussion

Increasing insight into cognitive functioning, and therefore increasing the chances of an early diagnosis of dementia can ensure that any treatment will help stabilize or slow down the degenerative process of dementia (Rasmussen et al., 2019). A lot of research has been done on reaction time on single decisions (Schmiedek et al., 2007; Wagenmakers et al., 2007; Forstmann et al., 2016). Ratcliff et al. (2010) also showed that aging is an important factor for decreased performance on single reaction time tasks. However, single decisions might not contain the most predictive power of everyday cognitive functioning in people. The aim of this thesis is therefore to achieve a description of behavior, like chained decisions, that better resembles everyday functioning. With this, we hope to contribute to increasing the knowledge of WM, so that further research can be done to increase the knowledge about cognitive functioning. With this purpose in mind, we investigated the differences in the distribution of reaction time of single and double decisions and their relation to WM as a window on cognition. This was done by using a clinical task that measures the span of WM (Wechsler, 2012). Furthermore, novel computer reaction time tasks were used that consisted of color and contrast judgment tasks. Three levels were used in the task, single decisions, double independent decisions, and double dependent decisions. These tasks were used to get the drift rate, boundary separation, and non-decision time of RTs of the EZ-diffusion model (Wagenmakers et al., 2007). In this thesis, evidence is provided that there is an effect on all three parameters on single decision tasks compared to the double decision tasks. However, no effect was found between the double independent decisions and the double dependent decisions. Also, the link between the cost of making a double decision and the span of WM was non-significant although in the expected direction.

Looking at the results, firstly, no difference was expected on drift rate, boundary separation, and non-decision time between the single decisions and the double independent decisions (whether the task was on color or contrast). Because Fan et al. (2012) showed that there was a significant difference in RTs between independent and dependent decisions, it was therefore hypothesized that the RTs of independent decisions are in the same way as single decisions. However, the results showed that there was a significant difference between all three parameters in the color and contrast task on the single decisions and the double independent decisions. An explanation for these findings is that participants made the second decision already in their brain when making the first decision during the double independent reaction time task. This is in line with the PRP, which showed that people cannot process multiple independent stimuli when they are presented closely in time, it takes time to process multiple stimuli (Pashler, 1984). A recommendation for future research is to adjust the double independent reaction time task. By explicitly separating the two tasks (color and contrast), participants cannot already think about the second decision.

Secondly, a higher threshold was expected in the color task (first decision) on boundary separation on the double dependent decisions compared to the double independent decisions. The results showed that this effect was not significant although the direction of the effect was the expected one. Because during the dependent decisions the color and contrast tasks are related to each other, it was hypothesized that this ensured higher thresholds in the color task (*i.e.* as doing an error in the first decision increases the likelihood of an error on the second decision).

Thirdly, a lower drift rate was expected in the contrast task on the double dependent decisions compared to the double independent decisions. The results showed that there was no significant effect although, once again, the direction of the effect proved to be the expected one. Since color determined the contrast during the dependent decisions, it was therefore hypothesized that making the second decision is more difficult than when two decisions are independent of each other (Forstmann et al., 2016; Wagenmakers et al., 2007).

Fourthly, a longer non-decision time was expected in the contrast task on the double dependent decisions compared to the double independent decisions. The results showed no such effect although the direction of the effect matched the predictions. Since color determined the contrast during the dependent decisions, it was therefore hypothesized that making the second decision adds a new cognitive processing step implying converting the given color to the correct contrast task.

Fifthly, a linear relationship between the span of WM and the difference on drift rate on the double dependent decisions and the single decisions in the contrast task was expected. This effect was not observed although the estimate from the linear regression is in the expected direction. Since making two decisions have a higher cost of WM load than making a single decision, it was hypothesized that people who have a low WM span have a higher difference between the cost of making a double or single decision (Meiran, & Shahar, 2018; Wagenmakers et al., 2007).

Critical comments must be made on the results described above. In the reaction time tasks, task difficulty per participant was not taken into account. This means that every participant had the same opacity and contrast difference. Therefore, it could be that the reaction time task was too easy or too difficult for the participant. This could influence the reliability of the reaction time task (Field, 2018). A recommendation for future research is that before the main task begins task difficulty will be adjusted. A calibration task could be performed to adjust task difficulty to each participant. Furthermore, the low number of participants might contribute to the lack of a significant linear relationship between the span of WM and the difference on drift rate on the double dependent decisions and the single decisions in the contrast task. It reduced the power of our analyses and increased the margin of error (Field, 2018). For future research, it is therefore recommended to increase the sample size. Finally, there may be an experimenter effect. Since most of the participants were friends of mine it could have influenced the way how I dealt with them, unlike the participants I did not know. This could have ensured that friends of mine felt more at ease and less stressed and performed therefore better on the experiment. All these disadvantages may have affected the reliability and validity of the experiment. To our knowledge, this thesis was the first study that looked at how single decisions, independent decisions, and dependent decisions are related to each other, using the EZ-diffusion model. Follow-up research is therefore recommended to test these effects with a higher statistical power.

In conclusion, based on our results, it can be said that going from a single to a double decision is costly, even if it is independent. This research in cognitive functioning sheds new light on the way how different sorts of decisions are related. Expanding research about cognitive functioning will lead to a better understanding of cognitive functioning. This will ultimately increase the chances of an early diagnosis of dementia. Since aging decreases performance on the speed of WM and our population grows with an increased life expectancy, research into cognitive functioning must continue. Not only for the life of the person with dementia but also the lives of those close to them.

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Appendix

Assumption check lineair regression

Multicollinearity

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	,203	,074		2,746	,014		
	span	-,017	,015	-,286	-1,193	,250	1,000	1,000

a. Dependent Variable: difference

Independency of our residuals

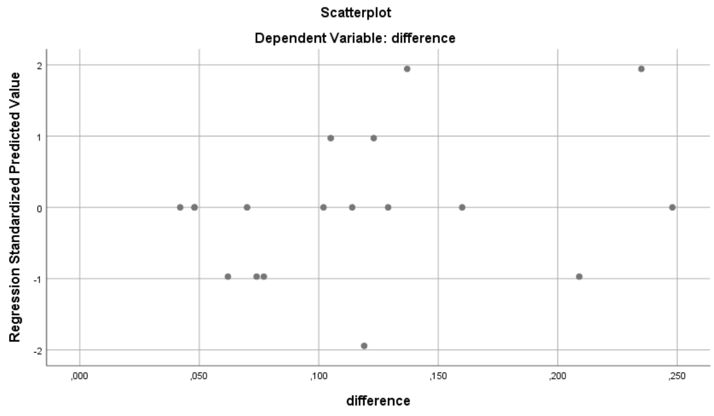
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,286[a]	,082	,024	,061635	2,123

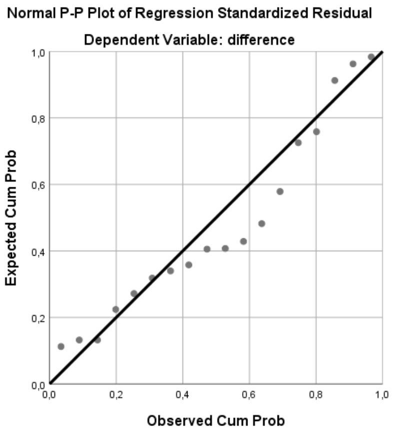
a. Predictors: (Constant), span

b. Dependent Variable: difference

Homoscedasticity



Normally distributed residuals



Linearity