Processing Speed and Comprehensibility of Visualizations and Texts

Michaela Tuscher*
Supervised by: Johanna Schmidt†

VRVis Forschungs-GmbH
Vienna /Austria

Abstract

As visualizations get more and more important in everyday life, it is crucial to find out how helpful they actually are, especially in comparison to text. This state-of-the-art report outlines if static visualizations or texts are processed faster by humans and which one is better comprehensible. For this purpose, 19 studies, two meta-analyses, and one article are discussed. In general, no global answer could be found as there were only a few studies directly comparing text to visualizations without additional text, and these studies had conflictive results. The majority of the studies compared text to text with additional visualizations, and showed their positive as well as negative impacts. When it comes to processing times, there are no comparative studies at all. Concerning comprehensibility, the studies showed some interesting results. If there are only visualizations or only texts, both seem to be equally well comprehensible. Adding visualizations to texts increases comprehensibility in most cases. While decorative pictures can lift the mood and increase learning performance, they can also divert the attention away from the important things. Also, especially younger children and poor learners can have problems with linking information from texts and visualizations.

Keywords: Visualizations, Texts, Processing Times, Comprehension

1 Introduction

'A picture is worth a thousand words', is a common saying. But how many words is a picture or a visualization actually worth and is there a way to measure this? Are humans better in processing visualizations or text and which one is faster and/or more accurate? Also, are visualizations or texts easier to understand? The answers to these questions get increasingly important as nowadays visualizations play a big role in everyday life.

A very widespread claim that can be found on multiple websites and also in some papers is the following one: 'Visuals are processed 60,000 times faster than text'. While the websites often link to each other as sources, some also link to scientific papers. However, there actually seems to be no scientific source behind this statement, since it cannot be found in any published paper and it is unclear where this claim originates from. There are even websites dedicated to find the source, but to date without success [15]. Therefore, the claim that visualizations are processed 60,000 times faster should be taken with a grain of salt. '90% of information transmitted to the brain is visual', is another statement often paired with the former one. Again, it is unclear if there are any quantitative studies that back up this claim. In favor of visualizations, it is also often stated on websites that 65% of the general population are visual learners. While different papers can be named as sources for this claim, it is actually not mentioned in any of the cited papers, or is mentioned, but without explaining where those numbers originate from. Another statement that is often cited, is, that the brain can identify images seen for as little as 13 ms. This statement is actually true and stems from a study by Potter et al. [19] which is discussed in detail in Section 2.1.

2 Studies

This section will discuss studies about the processing speed and comprehension of texts and visualizations. The section about comprehension starts with analyzing studies about how people judge the comprehensibilty of visualizations and texts, then presenting meta-analyses, before going over to studies directly opposing comprehensibilty of texts and visualizations, and concluding with studies using both, text and visualizations. A summary of the studies analyzed in this report can be seen in Table 1.

2.1 Processing speed

Dunn [5] tried to find better estimations for the claim that visuals are processed 60,000 times faster than text. In an article on a website they put together and compared the conclusions and results of different studies concerning processing times of written words and images. Among the compared studies are those by Thorpe et al. [22], Potter

*tuscher@vrvis.at
†jschmidt@vrvis.at

Study	Main Topic	Number of Participants	Text (and Length)	Visualization	Condition
Dunn [5]	PS	Comparative Website Article			
Thorpe et al. [22]	PS	15	-	Photographs	Vis.
Potter et al. [19]	PS	32 + 32	-	Photographs	Vis.
Hauk et al. [10]	PS	20	3 – 6 Letter Words	-	Text
Dyson and Haselgrove [6]	PS	24	Articles (up to 1000 Words)	-	Text
Serra and Dunlosky [21]	CJ	80 + 120	Science Text (ca. 500 Words)	Photograph or Diagram	Text vs. Text + Vis.
Ikeda et al. [11]	CJ	60 + 46	Science Texts (7 Paragraphs x ca. 300 Letters)	Image or Bar Graph	Text vs. Text + Vis.
Levie and Lentz [14]	C	Meta-Analysis			
Guo et al. [9]	C	Meta-Analysis			
Chibana [4]	C	1428	Articles (250 Words)	Infographics	Text vs. Vis.
Petrova and Riekhakaynen [18]	C	22	Science Texts	Infographics	Text vs. Vis.
McCrudden et al. [16]	C	47 + 55	Science Text (1385 Words)	Diagram	Text vs. Vis., Text vs. Text + Vis.
Branch and Riordan [3]	C	274	Science Text (3 Pages)	Diagram	Text vs. Vis.
Erfani [7]	C	65	English for Special Purposes Texts	Pictures	Text vs. Text + Vis.
Pan and Pan [17]	C	95	Text about Traffic Accident (123 or 162 Words)	Drawings	Text vs. Text + Vis.
Ardasheva et al. [1]	C	174	Science Texts (424 – 444 Words)	Photograph or Drawing	Text vs. Text + Vis.
Jian and Ko [12]	C	42	Science Texts (400 + 414 Chinese Characters)	Photograph or Diagram	Text + Vis.
Firat [8]	C	99	Maths Text Questions	Charts and Pictures	Text vs. Text + Vis.
Berends and van Lieshout [2]	C	135	24 Maths Text Questions	Drawings	Text + Vis.
Schnotz et al. [20]	C	40	Science Texts (36 – 116 Words)	Photograph, Diagram, Map or Graph	Text + Vis.
Lenzner et al. [13]	C	30 + 57 + 194	Science Texts (1130 Words)	Photograph or Diagram	Text vs. Text + Vis.
Yarbrough [23]	C	89	Management Texts	Infographics	Text vs. Text + Vis.

Table 1: The studies in this report. Topic: C = Comprehension, PS = Processing Speed, CJ = Comprehension Judgement.

et al. [19] and Hauk et al. [10]. Based on the results of those studies, Dunn estimates image processing times to be between 13 ms and 150 ms, the time to process a sentence containing 25 words to be between 3.75 seconds and 7.5 seconds, and to process a sentence with 8 words between 1.2 seconds and 2.4 seconds. Utilizing those numbers, Dunn draws the conclusion that images are processed between 8 and 577 times faster than words and rounds it to between 6 and 600 times.

Thorpe et al. [22] conducted a study where the processing speed of images was measured. Between 700 and 2000 photos were shown to the participants who had to judge if the photo contained an animal or not by pressing or releasing a button. The results indicated that even if a photo was only shown for 20 ms, the participants were able to categorize 94% of the images correctly (on average).

Another study about the processing speed of images was conducted by Potter et al. [19]. A series of six or twelve pictures, in which each picture was presented for 13, 27, 53 or 80 ms, was shown to the participants, who had to detect if a target picture specified by a name, e.g., 'campfire', was in the stream of pictures. The target name was either shown before or after the stream. If the stream contained the picture, the participants had to identify this image out of two images with the same target name. The process is illustrated in Figure 1. The detection rate was nearly always better when the target name was shown before the stream, no matter the showing durations and if it contained six or twelve pictures. The only exception was the six picture stream with a showing duration of 13 ms.

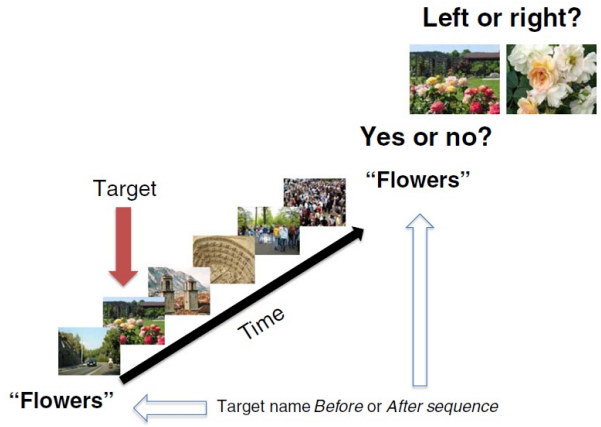

Figure 1: Illustration showing how the participants had to detect a target picture in a series of six pictures in the study by Potter et al. [19].

Also, participants were able to detect targets with a likelihood of significantly more than 50%, even if they only saw them for 13 ms, but the longer they saw them, the higher became the detection rate.

Hauk et al. [10] made an experiment about visual word recognition speed. Their participants had to decide by pressing a button if a word was an actual English noun or an invented word. The words were between three and six characters long and each was shown for 100 ms. Concerning the reaction times, the results show that participants were significantly faster for words than for invented words and also the error rate was higher for invented words.

Dyson and Haselgrove [6] investigated the effects of reading speed on reading comprehension. As training, participants had to read a text in twice their normal reading speed. For the subsequent study three documents, containing up to 1,000 words, had to be read in normal speed and three at a faster speed while the time was measured. After each document the participants answered multiple-choice questions about the content, and specified if certain sentences appeared in the text or not. On average, in the normal reading speed, 4.06 words were read per second compared to the faster one with 7.66 words per second. The comprehension scores as well as recall of certain sentences were better at the normal reading speed in all cases.

To summarize, studies so far did not directly compare text and visualization processing times. The only approach which tried to compare processing times by Dunn [5] took the results from different studies, that were originally not meant to be compared, were conducted under different conditions, and are, therefore, not really comparable. Consequently, only a rough estimate can be made for the differences between processing times of visualizations and texts. Only photographs have been used in the studies (no data visualizations) [19, 22]. Hence, measurements for further and different visualization types like graphs or diagrams are needed. Also, it has to be pointed out that in some of the studies [19, 6] the participants were trained to achieve high processing speeds, for example, by training to read twice as fast, or shortening viewing intervals for photos further and further. The performance and comprehension of the contents were always better when the participants were able to process the materials for a longer time period.

2.2 Comprehension

In this section, studies about the comprehension of visualizations and texts are presented.

2.2.1 Judgement of Comprehension

The following two studies analyze how people judge the effects on comprehension of visualizations or text versus their actual effects.

Serra and Dunlosky [21] conducted two experiments. In the first one, students had to study a text about how lightning storms develop, either accompanied by diagrams or not. The participants had to judge how good they think they will comprehend the materials before they began, after each paragraph, and after they were finished with studying. Subsequently, they had to answer comprehension questions. The results show that the students thought that additional diagrams would lead to better comprehension. An analysis of the latencies indicated that more time was spent on the text with diagrams compared to text-only, but additional diagrams also lead to a better performance on the comprehension questions. In their second experiment a third group was added which saw images of lightning strikes instead of diagrams. The group with images estimated their comprehension to be even a bit better than the one with diagrams did. However, the best performing group was the one that used text with diagrams, while the text-only group performed worst. Also, the total studying time was the highest for the group with images.

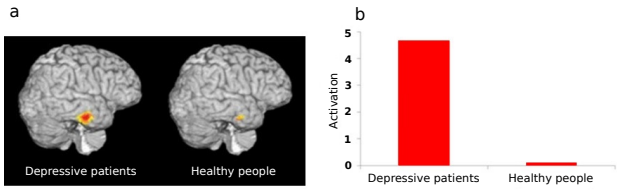

Figure 2: Examples of a) brain images and b) bar graphs used by Ikeda et al. [11].

The study by Ikeda et al. [11] investigated their participants' judgement of comprehension before and after reading a text. In a first experiment, the participants got either only a text or text accompanied by brain images and had to answer comprehension questions afterwards. The results confirm that the text accompanied by images was judged to be better comprehensible than the one without images, but there was no significant difference between the two groups. In a second experiment, texts with brain images or bar graphs were used. Examples can be seen in Figure 2. The text with images was believed to be better comprehensible, but again, there was no difference in actual comprehension. Therefore, the authors concluded that judgements about comprehension conflict actual comprehension and that in this study images and bar graphs did not help the participants to understand the text.

Both studies found that people judge visualizations to increase comprehension, but their expected positive effects might be inflated compared to the actual ones.

2.2.2 Meta-Analyses

Meta-analyses compare and summarize results of different studies about a topic and use statistics to form conclusions.

Levie and Lentz [14] did a review and summary of 55 studies conducted between 1938 and 1981, which examined if illustrated text helps with learning as opposed to text alone. They did not consider studies using graphs, charts or diagrams - instead, most of the studies in their report used either photographs or drawings as illustrations. The result of 46 comparisons from 23 studies about learning information from text and illustrations, was that 45 reported better group means for illustrated text than for text alone. In 39 cases the differences were statistically significant. On average, the scores of the groups with illustrations were 36% better. In another comparison of 10 studies, examining if illustrations have detrimental effects when they are only decorative, it was concluded that illustrations have no effect in this case. Furthermore, in 48 comparisons that did not fit into the groups with the other comparisons, 38 favored the illustrated texts.

Guo et al. [9] did a meta-analysis about the impact of graphics on reading comprehension where they analyzed 39 studies conducted between 1985 and 2018. Most of them compared the usage of text-only with text presented together with graphics. Just two studies investigated the impact of text-only versus graphics-only. In the meta-analysis it was concluded that graphics overall had a moderate positive effect on reading comprehension. Also, the comprehension improved if pictures were added to the text as opposed to combinations of different graphic types. Comparing the effects of different graphic types to each other, all of them, i.e., pictures, pictorial diagrams, and flow diagrams, showed similar beneficial effects on comprehension. No significant differences between grade levels of the participants were found. However, the authors state that something to be considered, is, that the graphics for the studies were specifically crafted to be helpful for learning the texts, and were also of high quality and created by experts. So the positive effects that were found may be inflated and it is hard to say if they are universal and applicable for visualizations in general like typical graphics in textbooks or journals.

In general, both of the discussed meta-analyses came to the conclusion that illustrations have at least moderate positive effects on the comprehension of the materials.

2.2.3 Visualizations-only versus Text-only

Most of the studies that compare the comprehensibilty of visualizations as opposed to text, compare texts to texts with different additional visualizations, while only a few compare text to visualizations without text. The following studies directly oppose text-only to visualizations-only.

Chibana [4] published a study where each of the 1,428 participants got a total of six articles. The articles were either presented as a text containing 250 words, or one of six different infographic types with the same information as in the text. Afterwards, the participants had to answer comprehension questions. The results show that, depending on infographic type, participants sometimes scored higher and sometimes lower on the comprehension questions than participants that had to read a text. The same accounts for their recall of the material. However, in most cases differences were insignificantly small.

Petrova and Riekhakaynen [18] conducted an eye-tracking study with 22 students between 14 and 17 years comparing infographics to text, and also measured processing times. All students got two different infographics and two different texts, and had to answer questions about the content and difficulty afterwards. For three of the four assignments there were more correct answers, and the difficulty was estimated to be lower for the infographics than their textual counterparts. However, the questions concerning general understanding were answered more accurately in three of four cases when text was provided. The authors also stated that text is better suited for reaching conclusions while infographics are better for remembering and understanding local parts. Concerning the total processing time, there was only a significant difference in one case where the text was long and, therefore, more time was spent on the text as opposed to the infographic. It was concluded that the processing time rather depends on text characteristics like topic, size, and design, and not so much on the format - infographic or text. Furthermore, text areas in infographics tended to be observed longer than picture areas, of which some had no fixations at all.

McCrudden et al. [16] studied the effects of causal diagrams on text learning. This study was part of the meta-analysis by Guo et al. [9] from Section 2.2. They used causal diagrams which show which causes lead to which effects by linking them with arrows, i.e., in their study a diagram depicting the effects of space travel on the human body. In a first experiment the participants had to read and memorize the contents of a text in ten minutes, either with or without a diagram, and answer retention and comprehension questions afterwards. There were no significant differences in memory or comprehension concerning the main ideas of the text, but the causal sequences were understood better with a diagram. Also, the more complex a sequence, the more helpful the diagram. The second experiment was conducted with diagram-only versus text-only conditions using the same materials as in the first experiment. Even though one group only had a diagram and no text, there were no significant differences in comprehension between the groups. Therefore, it was concluded that a good diagram can contain as much information as the corresponding text, and text would not be required.

The second study from the meta-analysis by Guo et al. [9] directly comparing texts to visualizations was conducted by Branch and Riordan [3]. They examined the effects on comprehension using flow diagrams or texts with or without study questions, and different time intervals to study the materials. The participants either had to learn a flow diagram or a text containing the same information, and some of them got additional study questions afterwards. These were meant to focus the attention on the most important parts. For learning and answering the study questions, the students got either 10 or 20 minutes. According to the results of the post test, the group which only saw the diagram performed on average better than the text-only group for a learning time of 10 minutes, however, for a learning time of 20 minutes, it was the opposite.

To summarize, two of the discussed studies [4, 16] mostly found no significant differences between comprehension or recall of visualizations and texts. The other studies [18, 3] had conflictive results that favored visualizations in some cases and texts in others. The visualizations used in the studies were infographics, causal diagrams, and flow diagrams. However, results for other visualization types would be interesting too. Since two studies used infographics [4, 18] it has to be mentioned, that infographics contain graphics as well as text. Therefore, they might not be suited for directly comparing text to visualizations in terms of comprehension or processing speed.

2.2.4 Text and additional Visualizations

The remaining studies compare the effects of text to those of text with additional visualizations and analyze impacts for English learners, as well as for different age groups.

Erfani [7] conducted a study in which Iranian students were divided into two groups, both were taught for twelve weeks either by using only English texts or English texts with additional pictures. Afterwards, they had to do a test. The results show that pictures enhanced the students' reading comprehension. The instructor noticed that students, who were taught with pictures, participated more in discussions and were more attentive.

The effects of pictures in texts for low proficiency English learners were examined by Pan and Pan [17]. Their participants were Taiwanese college students. Each of them got an English reading text describing a traffic accident, either on a high or low difficulty level, and with or without drawings visualizing what happened in the accident. The students had to translate the English text into Chinese as well as rate the pictures' helpfulness. It can be seen in the results that the translation scores were significantly higher with additional pictures for both difficulty levels. The students overall agreed that pictures helped them understand the text better, but to different extents compared between high and low level texts. Students with the low level text found them more helpful for guessing the meanings of unknown words in the text, while students with the high level text found them more helpful for understanding what happened in the text.

The results of a study with seventh-grade English learners by Ardasheva et al. [1] were different than those of Erfani [7] and Pan and Pan [17]. Two physics texts, which were either accompanied by photographs and drawings, or not, had to be read by the participants. The drawings and photos were labeled and visualized the contents of the texts. After reading the texts, the students had to answer comprehension questions and questions about their interest in physics. Concerning the comprehension scores as well as triggered interest, the results of both groups show no significant differences, but a small tendency favoring the group without visuals. The authors state that no positive effects of the utilized visuals in this study were found.

Jian and Ko [12] did an eye-tracking study with 10-year-old children about reading comprehension of illustrated biology texts. The children were separated into two groups depending on their reading abilities. Afterwards, they had to read the same two illustrated science texts, having different complexities, and answer comprehension questions. The children with higher reading ability performed better on all questions and both groups did better on the easier text. While both took roughly the same amount of time for reading, the high ability group rather focused on the difficult text and pictures, while the low ability group was more focused on the text in general, and especially the easier one. The authors concluded that children with lower reading ability had problems understanding the illustrations and linking them to the text.

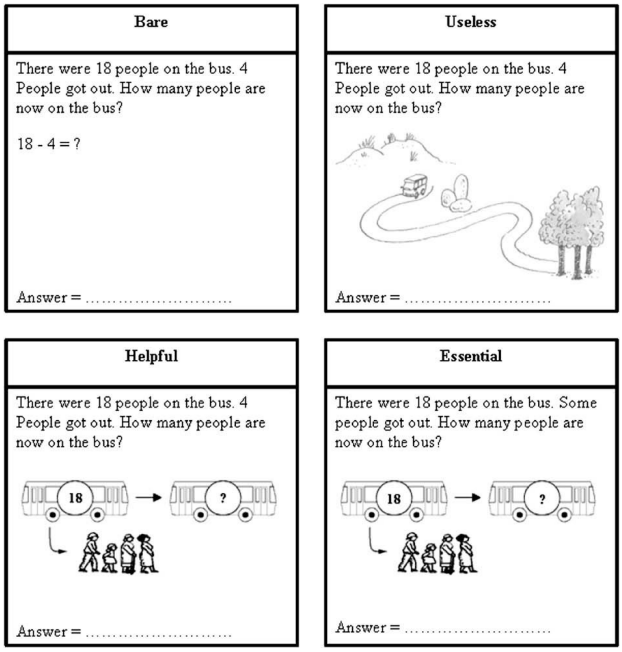

Figure 3: Examples of the different illustration types used in the study by Berends and van Lieshout [2].

Firat [8] analyzed the effects of real and model visuals on the test performance of elementary students from grade five. The students got one of three different forms of maths tests, either with only text, text and model visuals or text and real visuals. It was found that students who did tests with visuals had higher scores than those who only saw a text. Also, the average time needed to complete the test was the highest for the test with model visuals and the lowest for the test with real visuals.

Berends and van Lieshout [2] conducted a study with fifth graders and maths questions, in which the speed and accuracy of solving arithmetic word problems presented with four different types of illustrations were measured. The illustration types were 'bare', which were, for example, equations for the word problems, 'useless' decorative illustrations, 'helpful' illustrations representing what was written in the word problem, and 'essential' illustrations that contained additional information. Examples are shown in Figure 3. The participants saw the same 24 arithmetic word problems accompanied by the different illustration types. Dependent on their score in a standardized maths test, they were assigned to the good or poor arithmetician group. Results show that the scores of both groups were lower and the time they needed was higher for the word problems with essential illustrations compared to the other ones. Word problems with 'bare' illustrations were solved fastest. The authors state that using illustrations together with word problems does not necessarily improve the performance but may even have a negative impact, especially if the presented illustrations are irrelevant for solving the problem and for the poorer arithmeticians.

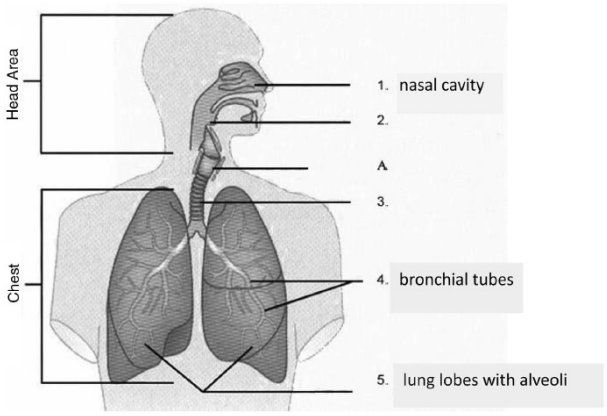

Figure A3. Respiratory system: The respiratory system ensures that air enters the body when inhaling and that it leaves the body when exhaling. As shown in the diagram, the air passes through the respiratory system, which is labeled with numbers representing the specific respiratory organs. Number 2 represents the pharynx. The trachea (No. 3) connects the respiratory organs in the head area with the respiratory organs in the chest. To prevent choking, the epiglottis (A), which is not part of the respiratory organs, covers the entrance of the trachea. In the chest, the trachea bifurcates into two main bronchial tubes, which in turn branch off, ending in millions of air-filled alveoli. All of the alveoli together make up the two lungs lobes.

Figure 4: A diagram as visualization and image caption as textual part, used in the study by Schnotz et al. [20].

In an eye-tracking study by Schnotz et al. [20] the authors examined students' strategies to integrate information from text and pictures. The participants were from grades five and eight from the higher and lower tier of the German school system. Four texts with additional pictures that illustrated information not mentioned in the texts were presented to the students together with three comprehension questions with growing difficulty. To answer the questions, the text as well as the pictures and how they are linked had to be understood. In most cases, their provided texts were image captions for the visualizations. An example for this can be seen in Figure 4. The authors conclude that texts are used for global understanding, while pictures are used for selective processing like finding the relevant information for a task. Concerning the measured processing speeds, the average time for processing text, pictures and the questions was 652 seconds. Students from the higher tier gave more correct answers and needed less time for reading than students from the lower tier. The text fixation times were always highest when answering the first question, even though it was the easiest one, and the lowest for the last question, the most difficult one. Concerning fixations on pictures, it was the same effect for students from the lower tier while students from the higher tier had the lowest fixation times on the picture during answering the second question and the highest on the third one.

The role of decorative and instructional pictures in learning was examined in three experiments by Lenzner et al. [13], which were conducted with seventh and eighth graders. In a first eye-tracking experiment the students got presented either a text with decorative or instructional pictures or both. For a text about shadows, for example, the instructional picture was a diagram illustrating how a shadow forms, while the decorative picture showed trees throwing shadows. It was found that decorative pictures were only given attention at the beginning and were afterwards ignored, while instructional pictures were viewed throughout reading the whole text and also two or three times longer compared to decorative ones. The second experiment using the same materials as the first one indicated that decorative pictures bettered the students' mood and lead to more alertness and calmness compared to instructional pictures. The last experiment, with an additional group that only got a text without pictures, showed that students also perceived the learning material to be less difficult if decorative pictures were present and more interesting when they had instructional pictures. Also, the learning performance was better with instructional pictures, while decorative pictures were found neither to be harmful nor helpful for learning. However, combined with decorative pictures, the instructional ones lead to an even better learning performance.

Yarbrough [23] analyzed if infographics improve online learning. Infographics were used for weekly summaries of the content of an online course. Every week students could do optional quizzes about these infographics. At the end of the course the students were asked their opinions about infographics and especially about learning with them. The study showed that a majority of students found them helpful for summarizing and remembering key concepts, and learning for the final exam. Compared to the same section of the course without infographics, the final course grades for the section with infographics were overall better.

To summarize, an abundance of studies compares text with additional visualizations to text-only. In these cases, it may be hard to measure the effects of visualizations alone, because the additional text also contributes to comprehensibility, and it is especially hard to tell how well a visualization without text would be comprehended. The fact that the attention would have to be split between text and visualizations is also the reason why these studies are not viable for comparing processing times of visualizations to those of texts.

In general, the studies using text with additional visualizations mostly found positive effects for recall and comprehension. However, also negative effects of visualizations were mentioned. Some of the studies concluded, that particularly younger children or poor learners can have difficulties in integrating information from text and visualizations and understanding the correlations [12, 2, 20].

Two studies analyzing the effects of visualizations for English learners concluded that they were helpful [7, 17], while one found, that the visualizations had no positive effects at all, and the study even had a small tendency favoring texts [1].

Also, especially concerning decorative visualizations, the studies showed conflictive results. It was found that they can divert the attention from the important things and time may be spent unnecessarily to process the visualization [2]. On the contrary, also positive effects, like an increase in alertness, calmness, and learning performance were found [13].

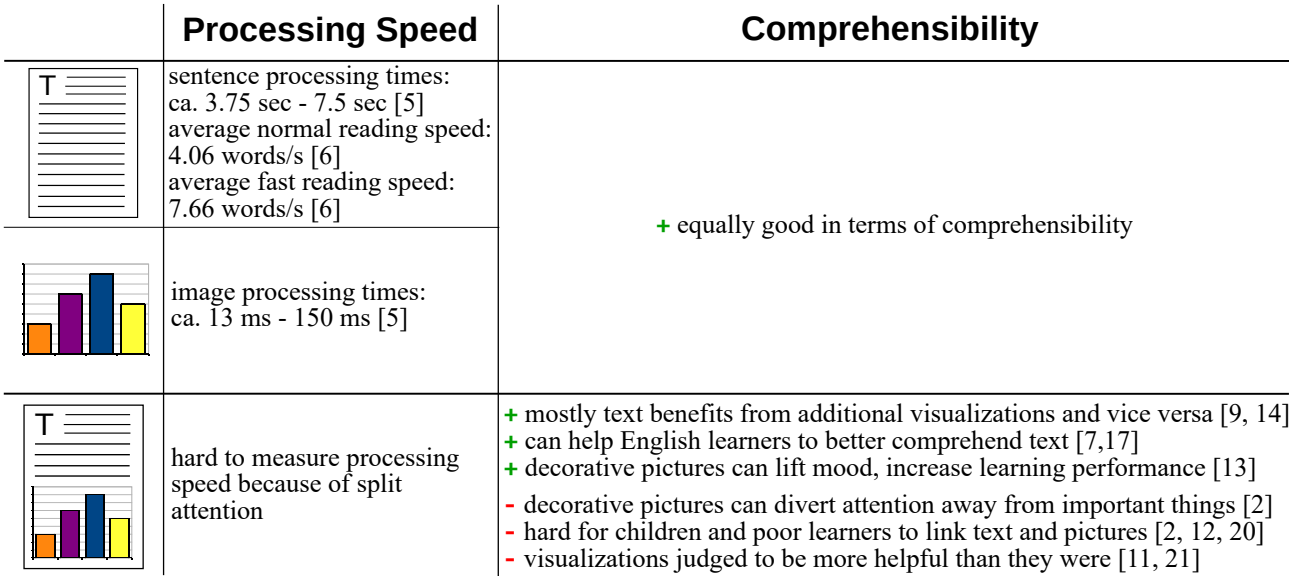

Figure 5: Visual summary of the most important conclusions.

3 Conclusions

Due to the ever-growing importance of visualizations, it is crucial to find out how fast visual representations can be processed and how comprehensible they are, especially in comparison to text. While many frequently-used statements about the positive effects of visualizations can be found on the internet, many of them are exaggerated or lack scientific sources for their claims. Therefore, it is important to have a look at the studies examining these questions.

Figure 5 shows a visual summary of the most important conclusions. Looking at the results of the meta-analyses and studies discussed in this report, it can be said that if there is only a text or a visualization, both seem to be equally good in terms of comprehensibility. Also, when visualizations are added to texts, they increase the comprehension in most cases. However, it has to be stated that most studies only found very small differences between comprehensibility of texts and visualizations. Some studies even showed that the groups working with texts performed better. It was concluded that people often judge visualizations to be more helpful than they actually are. Also, especially for young children, poor learners, and when using decorative visualizations, some negative effects were found.

In terms of processing times, photos seem to be processed faster than texts, but rather 6 to 600 times faster, not 60,000 times. It has to be stated, that there is a difference between recognizing a given target in a photo versus being able to interpret, for example, a diagram. So the processing speeds for other visualization types might be very different.

The goal was to find out if visualizations or texts are better comprehensible and which one can be processed faster. Although some interesting conclusions were found, no satisfying answers for the original questions can be given. Concerning processing speed, no comparative studies were found at all. In terms of comprehensibility, only four studies directly compared texts to visualizations without text, and they had conflictive results. Also, while the influence of the content was not discussed in the studies, it would be interesting to know which role the content plays, because some information might be easier to be communicated through visualizations or texts. It is also very likely that the type of visualization is important for comprehensibility and processing speed. Therefore, a study would be required which directly compares text to visualizations in terms of processing times and comprehension, while also analyzing the influence of the type of content and visualization type.

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