Underspecification and communicative efficiency of visual affixes of motion in comics

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Abstract

In a corpus of 331 comics, we analyzed the size and frequency of two visual affixes in comics: motion lines (trailing behind movers) with the meaning of directed motion and circumfixing lines (imitating the contours of a mover) with an underspecified meaning of motion. Given that the meaning of circumfixing lines is underspecified compared to motion lines, we asked whether their sizes and frequencies behave in communicatively efficient ways consistent with ambiguous words in language. We hypothesized that circumfixing lines should be smaller and more frequent than motion lines, in line with the ambiguous words being shorter and more frequent than less ambiguous words in spoken language. We found that circumfixing lines are smaller but not more frequent than motion lines. We argue that circumfixing lines are smaller than motion lines because of their underspecification and lower information content and we discuss possible reasons for their lower frequency.

Keywords: underspecification; communicative efficiency; ambiguity; length; frequency; visual language; comics; motion lines; circumfixing lines.

Introduction

Communicative efficiency

The wealth of research on spoken language has shown that many areas of language are modulated by communicative efficiency (Gibson et al., 2019), from phonetics (e.g. Priva, 2017) to lexicon (e.g. Kanwal et al., 2017; Kemp et al., 2018), word order (Maurits et al., 2010), and the grammatical marking (e.g. Kurumada & Jaeger, 2015; Levshina, 2022a; Mollica et al., 2021), among others. One of the most studied domains in the area of communicative efficiency is the Zipf's Law of Abbreviation (Zipf, 1935) or the tendency for more frequent words to be shorter than less frequent words. This law has been shown to hold across numerous human languages (e.g. Bentz et al., 2016; Levshina, 2022b; Piantadosi, 2014; Piantadosi et al., 2011) and even signals in animal communication (Ferrer-i-Cancho et al., 2013). Zipf (1949) hypothesized that the law of abbreviation follows from the principle of least effort, or the tendency to be as economic as possible, which is simultaneously impacted by the competing pressure to be as informative as possible.[1] While speakers try to reduce their effort in producing speech, thus making words shorter, hearers need as much information as possible to decode the signal, which raises the pressure for words to be longer. Longer words can then be more easily understood than shorter words in the communicative channel that is often disrupted by "noise" that can make the decoding of the transmitted information harder.

In addition to frequency, the higher predictability of a word in context has also been found to correlate with shorter length (Gibson et al., 2019; Piantadosi et al., 2011).[2] In line with this, Mahowald et al. (2013) found that speakers tend to choose the shorter form of a word, e.g. "chimp" instead of "chimpanzee", when the context is more predictive (e.g. in a text about primates). In a predictive context, a word with a contextually relevant meaning is more accessible and more expected to occur. Thus, although a shorter word conveys less information, in a predictive context the hearer is likely to understand it even in a noisy channel due to its higher accessibility. Given that shorter words contain less information, they tend to be more ambiguous (Zipf, 1949); for example, "a" is more ambiguous than "laptop" in English. Piantadosi et al. (2012) further tested this by teasing apart different factors that lead to ambiguity and showed that longer words have fewer senses or meanings, i.e., are less ambiguous, than shorter words in English, German, and Dutch. They argue that frequent and short words have more meanings because they are easier to process overall.

There is ample evidence that the principles of communicative efficiency are also at play in multimodal communication (Grzyb et al., 2024), such as sign language (Slonimska, 2022), gesture (Rasenberg et al., 2022), and comics (Cohn, Schilperoord, & Cardoso, 2026), where highly abstract visual affixes of motion that resemble grammatical encoding in spoken language are used more frequently when they mark unexpected information (Krajinović et al., 2025). However, there are different aspects of grammatical marking in visual meaning-making which have not been tested in depth before. In this paper, we focus on two visual affixes of motion in comics and ask whether the little understood differences in the meaning and ambiguity of these affixes can be explained by the

[1]In this view, the principle of least effort causes the inverse relationship between frequency and length. In this paper, we do not hypothesize on the causative directionality of the Zipf's Law of Abbreviation. While it seems plausible that high frequency drives the shortening of the words, both frequency and length are modulated by cognitive and functional pressures in language evolution.

[2]Gibson et al. (2019) and Piantadosi et al. (2011) argue that the predictability of a word correlates better with shorter word length than frequency does, while others (Levshina, 2022b; Meylan & Griffiths, 2021; Pimentel et al., 2023) showed that frequency of a word correlates better with its length.

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measures of communicative efficiency, i.e. their sizes and frequencies. We explain this in detail in the next section.

Visual affixes of motion

The visual affixes we focus on in this paper are motion lines trailing behind a mover, i.e. the moving entity (Figure 1a and 1b), and circumfixing lines surrounding the mover (Figure 1c and 1d). The reason we analyze them as affixes of visual language equivalent to grammatical morphemes in spoken language is because they do not have any meaning on their own unless they are attached to a stem, i.e. a figure or an object (Cohn, 2013). Moreover, both motion and circumfixing lines are highly abstract and have shapes and sizes that do not correspond any identifiable real-world phenomena, unlike for example drawn figures that represent people or animals (see Figure 1). This high degree of grammatical meaning is the reason we focus on motion and circumfixing lines and not on other types of lines that indicate motion with a higher degree of iconicity, such as lines depicting speed on the characters or in the environment mimicking the blur of fast speed (cf. Hacımusaoğlu et al., 2025).[3] Motion and circumfixing lines are the most frequent motion affixes in comics (Hacımusaoğlu et al., 2025). The comparison of motion and circumfixing lines is also of particular interest because they are minimally formally different, as they are both drawn as lines and they both attach to the stem in a formally similar way–barely or not touching the figure (cf. Figure 1).

Motion and circumfixing lines have distinctive features. Motion lines trail behind a mover and indicate motion of a moving entity over a path, shown partially or fully, as in Figures 1a and 1b. Because of this meaning, motion lines indicate the direction of movement in the direction opposite of the location of the lines, as has been shown in various experiments (Kawabe et al., 2007; Kim & Francis, 1998).

Circumfixing lines imitate contours of the mover and are typically placed on both sides of the mover, orthogonal to the direction of motion, as in Figure 1c and 1d. Therefore, they mark motion without specifying the direction, and the movement they indicate can be interpreted as iterative (e.g., back and forth). More rarely, circumfixing lines can be placed on only one side of the mover and then some directionality might be inferred (Hacımusaoğlu et al., 2025).

While motion lines have been fairly well studied in psychological experiments, especially regarding their processing and their meaning of directionality and speed (Cohn & Maher, 2015; Hacımusaoğlu & Cohn, 2023; Hayashi et al., 2012; Ito et al., 2010; Kawabe et al., 2007; Kim & Francis, 1998; Xu et al., 2025), the meaning of circumfixing lines as a distinctive type of lines is still little understood. Only a few quantitative corpus studies tested some differences in meaning between motion and circumfixing lines, which we discuss next.

[3]In the case of these more iconic types of lines, their sizes scale directly with the size of the depicted characters and the environments and would thus not be an appropriate object of study for our questions about size as a measure of communicative efficiency.

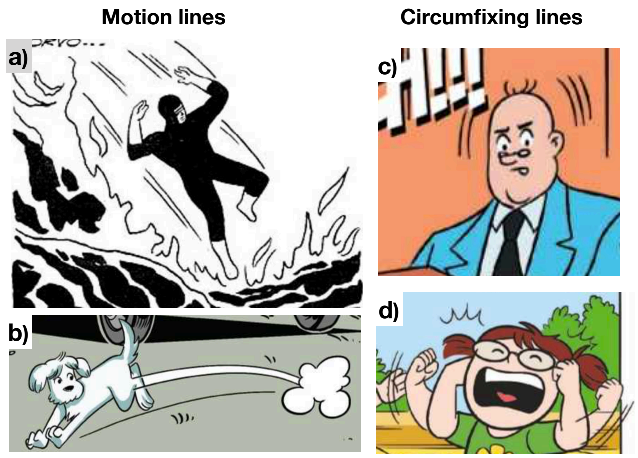

Figure 1: Examples of motion lines and circumfixing lines in the TINTIN Corpus; a) and b): motion lines trail behind a mover to indicate motion, c) and d): circumfixing lines mimicking the contours of a mover. (a) from "Raio Negro" by Gedeone Malagola and Momoki Akimoto (Brazil) (Malagola & Akimoto, 1968), and b), c), and d) from "Archie's Friend Scarlet" by Ray Felix and Fernando Ruiz, © Archie Comics (USA) (Felix & Ruiz, 2017)).

In a quantitative corpus study of comics, Hacımusaoğlu et al. (2025) analyzed several visual and perceptual features, such as directionality of motion, speed, presence of postural cues of the mover, i.e., moving entity, and marking of the route of the motion. They found that the presence of motion lines correlated positively with all these features, which indicates that motion lines express directionality and higher speed (depending on their number), and are typically used for the en-route segment of the motion. Circumfixing lines, on the other hand, when compared to motion lines, do not show a strong correlation with any of these annotated features. Also, in a principal components analysis that clusters co-occurring features automatically, circumfixing lines did not cluster with any annotated features in the corpus, while motion lines clustered with postural cues, explicit paths, and routes (Hacımusaoğlu et al., 2025). Based on the experimental studies on motion lines, we know that the higher quantity of motion lines is associated with the perception of higher speed (Carello et al., 1986; Gillan & Sapp, 2005; Hacımusaoğlu & Cohn, 2024), parallel to the corpus findings by Hacımusaoğlu et al. (2025), but that does not seem to be case for circumfixing lines (Krajinović et al., 2024). Xu et al. (2025, p. 307) also note that "orthogonal lines", which are equivalent to what we call circumfixing lines, "might function more as purely additional visual information, neither augmenting nor diminishing the action's perceived speed or force."

In another corpus study, Krajinović et al. (2025) have shown that motion lines are subject to animacy effects, while circumfixing lines are not. Since motion lines mark directed motion, they were more likely to mark the directed motion of inanimates than animates in the corpus, because directed movement is less expected from inanimates than animates (Opfer, 2002). Circumfixing lines, which do not mark specifically directed motion and are compatible with any type of motion, show no difference in the frequency of marking between animates and inanimates (Krajinović et al., 2025). The study by Krajinović et al. (2025) also showed that, at least with regard to animacy, motion lines exhibit communicatively efficient behavior by marking the unexpected, while circumfixing lines do not.

Based on these previous studies on the meaning of motion and circumfixing lines, circumfixing lines appear to be fairly semantically underspecified compared to motion lines. Crucially, circumfixing lines can also combine with motion lines, often without adding any meaning that cannot be inferred from the context. For example, in Figure 2a, circumfixing lines are used simultaneously with motion lines, which mark the traversed path leading to the interpretation of directed movement, additionally indicated by the figure's posture. The movement of the arms marked by circumfixing lines is already marked by the reduplication of the arms or polymorphism, highlighting even more the redundancy of using circumfixing lines. In Figure 2b, the circumfixing lines indicate the movement of the head, which can also be easily inferred by the fact that the character is walking away, which is unambiguous due to their posture and the presence of motion lines. Similarly, the circumfixing lines in Figure 2c only give an overall impression of movement, which is already indicated by posture and by the motion lines. Thus, circumfixing lines may be only used to emphasize the movement, which is already conveyed by other means. Intuitively, we might think that circumfixing lines mark a figure's back-and-forth or shaking motion, but Figures 2b and 2c show that this is not necessarily the case. We can conclude that circumfixing lines only contribute the meaning of signaling motion in general (cf. also Figure 3), even when that information is already clear in the context, thus without providing much new information.

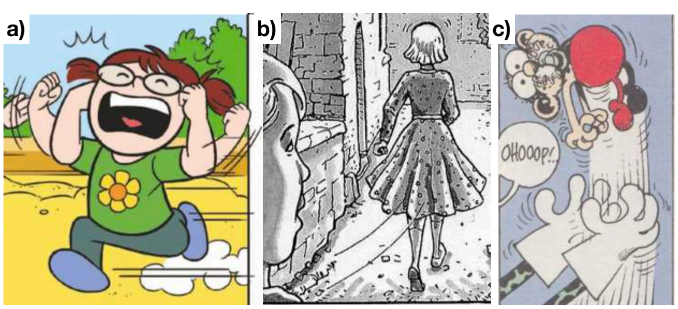

Figure 2: Example of motion lines co-occurring with circumfixing lines: a) From "Archie's Friend Scarlet" (USA) by Ray Felix and Fernando Ruiz (Felix & Ruiz, 2017), © Archie Comics, b) "El Arte de volar" by Antonio Altarriba (Spain) (Altarriba, 2009), c) "Zavallı Polat" (Turkey) by İmkansız Yolculuk (Yolculuk, 2017).

We analyze circumfixing lines as underspecified and not strictly ambiguous because they do not encode different senses (cf. Wasow et al., 2005). That is to say, it is not the case that they mark several specific aspects of motion. Instead, they do not seem to mark any, as they are compatible with many different and sometimes even opposing interpretations (e.g., shaking, directed or aimless motion, slight or intense movement etc.). This means that, while being underspecified, circumfixing lines allow for ambiguous interpretations,[4] as to for example the direction, speed, and (in)animate movement. Because of this, we expect that the features of ambiguous words also apply to the underspecified circumfixing lines.

Present study

The literature of communicative efficiency shows that the higher ambiguity of a word correlates with shorter length and higher frequency (Piantadosi et al., 2011, 2012; Zipf, 1949). Thus, in this paper, we ask whether the length (calculated as size) and frequency of motion and circumfixing lines might explain why circumfixing lines are so highly underspecified and convey much less information than motion lines. Since circumfixing lines allow for more ambiguous interpretations than motion lines, we expect that they are shorter and more frequent than motion lines on average. While it is beyond the scope of this work to test the information content of the lines in context, we are testing whether the *overall* higher ambiguity and semantic underspecification of circumfixing lines can be explained by their sizes and frequencies in the direction that is expected from the literature on communicative efficiency.

Based on this, we expected to find differences in size and/or frequency of motion lines and circumfixing lines. If we find that circumfixing lines are shorter and more frequent than motion lines, then their underspecification and low information can be interpreted as in relation to the same communicative efficiency process where ambiguous words are shorter and more frequent, equivalent to the shortest and most frequent words in spoken languages (Piantadosi et al., 2012), which are also the most polysemous[5] (Kuiper et al., 2018). Given that the visual style of comics has been reported to exhibit variability as a proxy for diversity across visual language structures (Cohn, 2023; Cohn, Schilperoord, & Cardoso, 2026), we might encounter differences across different visual styles of comics.

Methods

Our study uses a subset of the TINTIN Corpus of 1,030 comics from 144 countries and territories, which were annotated with the Multimodal Annotation Software Tool (MAST) (Cardoso & Cohn, 2022). In this study, we analyzed 331 from the TINTIN Corpus annotated for motion events, including all the instances of motion lines and circumfixing lines. This subset includes comics from 81 different countries and written in 35 languages (see Figure 4).

[4] Compare with the English word "sibling" as underspecified for gender and allowing for an ambiguous interpretation of gender (cf. Sennet, 2023).

[5] Polysemous words have more than one sense or meaning.

Figure 3: A segment from "El Arte de volar" (Spain) by Antonio Altarriba (Altarriba, 2009) in the Multimodal Annotation Software Tool (MAST). The regions in blue are annotated according to the annotation schema for motion events.

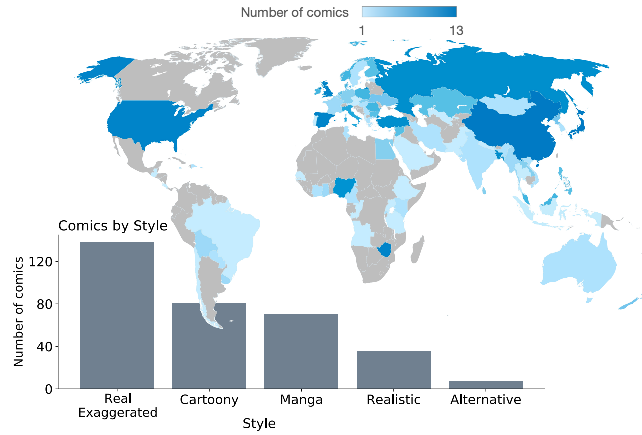

Figure 4: World map and histogram of countries and visual styles, respectively, represented in our sample of 331 comics.

Motion events in the TINTIN Corpus were annotated using the annotation schemes of "Visual Language Theory: Morphology: Motion Events v.2" (Hacımusaoğlu & Cohn, 2022a) and "Semantics: Path Structure v.2" (Hacımusaoğlu & Cohn, 2022b). All lines and moving entities, which we refer to as movers, are annotated manually as regions on the comic page, as shown in Figure 3. The regions of movers receive an annotation of a "Mover (figure)" or "Mover (object)",[6] motion lines "Motion cues / Motion line" and circumfixing lines "Motion cues / Circumfixing lines". The rules for the annotations published in Hacımusaoğlu and Cohn (2022a) and Hacımusaoğlu and Cohn (2022b) were continuously discussed by the annotators to ensure consistency. The MAST software automatically calculates the percentage of the page area occupied by a region, which is a relevant feature for our analysis of the size of the lines. The dataset and our code for the statistical analysis is published in Krajinović et al. (2026).

In our analysis, we compared the motion and circumfixing lines according to their areas and frequencies in our sample of 331 comics. Given that our data consist of a visual medium composed of lines and shapes rather than linguistic units with discrete lengths (e.g., words), we map the area covered by lines on the page onto word length in text, using it as a proxy for length. Regarding the area analysis, we took the raw numbers of the relative area according to the line type and we fit a linear mixed-effects model with random intercepts for comic title.[7] Prior to model fitting, we excluded comics with fewer than four observations to ensure stable estimation. We also included global region and visual style as fixed effects because they have been shown to be possible factors of divergence between comics (Cohn, 2023). Global regions include Asia, Europe, Africa, Americas (i.e., North, Central, and South), and Oceania. Each comic is classified in one of these regions according to its place of publication. The categories of style we considered in our analysis are manga, cartoony, real exaggerated (superhero-like), realistic, and alternative. The styles of the TINTIN Corpus were determined by a combination of manual annotations and computer vision methods described in Titarsolej et al. (2024) and Cohn, Hendrickson, et al. (2026). We also modeled the interactions between fixed effects. To interpret the interaction between line type and region, we computed estimated marginal means (EMMs) for each line type within each region, marginalizing over style. All contrasts were evaluated using Wald z-tests, and p-values were adjusted for multiple comparisons using the Holm correction.

For the frequency analysis, we calculated the counts of circumfixing and motion lines per page and analyzed them with a generalized linear mixed model with a negative binomial distribution and log link. As in the area analysis, comic title was included as a random effect, while line type, region, and style were included as fixed effects. The model also included interactions between fixed effects. We then computed estimated marginal means to obtain model-predicted line frequencies, expressed as the expected number of lines on a typical comic page, after adjusting for region and style. We calculated the pairwise contrasts for line type, region, and style using Wald tests with Holm-adjusted p-values.

[6]We received a reviewer suggestion to include the distinction between "mover (figure)" and "mover (object)" as a fixed effect in our analysis. We could not do this with the current data, because the annotated regions associated with lines are not linked to the movers that they mark and doing so would require manual effort that is not feasible at the moment. However, the possibility that this animacy distinction has an effect on our results is rather low in our data, considering that a) objects are much rarer than figures, as they make only 13,5% (n=2820) of all movers and figures make 86,5% (n=18066) of all movers, and b) in the same dataset, Krajinović et al. (2025) found that objects are more likely to be marked by motion lines than figures are, and for circumfixing lines there was no difference in the amount of marking of figures and objects. Thus, figures were marked equally frequently by motion and circumfixing lines.

[7]The inclusion of the comic title as a fixed effect controls for the variance between comic books, including their length and panel count.

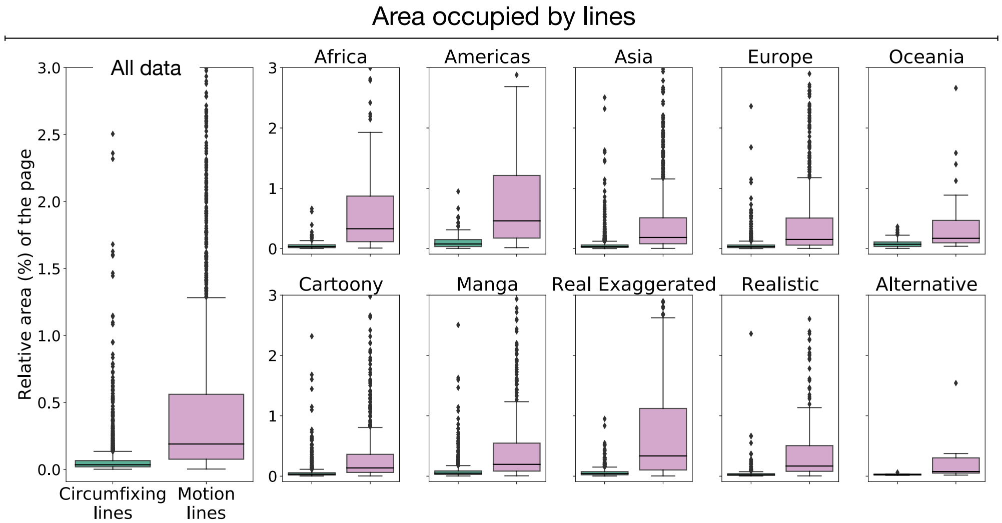

Figure 5: Relative areas (size) of circumfixing and motion lines in our sample, shown as all data and divided according to region and style. All data (left plot): circumfixing lines (n = 3182, Mdn = 0.035, M = 0.078), motion lines (n = 2400, Mdn = 0.19, M = 0.66).

Results

We asked whether there are differences in size and frequency of circumfixing and motion lines, calculated as the areas on the page and as the number of lines per page, respectively.

Figure 5 shows the distribution of observed relative areas of circumfixing and motion lines across regions and styles. We found a main effect of line type on area ($\beta = -0.309$, SE = 0.027, $z = -11.301$, $p < .001$). Circumfixing lines were smaller than motion lines. For style, only the real exaggerated style showed larger areas than the grand mean ($p = 0.013$); no other style differed significantly. Region did not show an overall main effect on area, but it interacted with line type: the area difference between circumfixing and motion lines was larger for Africa ($p = 0.001$).

Figure 6 shows model-predicted frequencies of circumfixing and motion lines, expressed as the expected number of lines per page. There was no significant main effect of line type, which means we observed no difference in the frequency between motion and circumfixing lines, $p = 0.387$. Across most regions and styles, the contrasts between the line types were not significant, although motion lines were numerically more frequent overall. Style had a main effect on the expected number of lines per page, $\chi(4) = 26.01$, $p < .001$, and interacted with line type. This interaction effect indicated that in the real-exaggerated-style comics, motion lines were more frequent than circumfixing lines ($p < .001$). The reverse trend was observed for manga ($p = 0.11$). In contrast, region did not show a significant main effect, $\chi(4) = 2.84$, $p = .58$, nor an interaction with line type.

Discussion and conclusion

In a corpus of 331 comics, we analyzed the size and frequency of two visual affixes in comics, motion lines (trailing behind movers) with the meaning of directed motion and circumfixing lines (imitating the contours of a mover) with an underspecified meaning of motion. Given that the meaning of circumfixing lines is underspecified compared to motion lines, we asked whether the underspecified semantics of circumfixing lines can be elucidated by the correlates of low information content observed in spoken language, namely word frequency and shorter word length.[8] We hypothesized that circumfixing lines should be smaller and more frequent than motion lines, in line with the ambiguous and lower-information words being shorter and more frequent than less ambiguous words in spoken language (Piantadosi et al., 2011, 2012; Zipf, 1949). We found that circumfixing lines are smaller but not more frequent than motion lines.[9] We discuss our results in more detail in the next paragraphs.

Our finding that circumfixing lines are smaller than motion lines on average is consistent with the expected communicatively efficient behavior equivalent to ambiguous words being shorter on average (Fröhlich et al., 2025; Piantadosi et al., 2012).[10] However, since circumfixing lines are the ones con-

[8]One hypothesized mechanism driving this relationship is the Uniform Information Density, which applied to lexical systems would mean that “the amount of information conveyed by a word should be linearly related to the amount of time it takes to produce— approximately, its length—to convey the same amount of information in each unit of time” (Piantadosi et al., 2011, p. 3526).

[9]The frequency result is in line with the initial findings by Hacımusaoğlu et al. (2025), where frequencies of different motion cues were calculated as averages per comic.

[10]Another explanation might be that circumfixing lines might simply mark movements that are iconically smaller than the movements marked by motion lines. Circumfixing lines do not necessarily denote “small” movement like shaking, as they are frequently used for “big” movements in combination with motion lines (cf. Figure 2). However, even if the movements they mark are indeed “smaller”

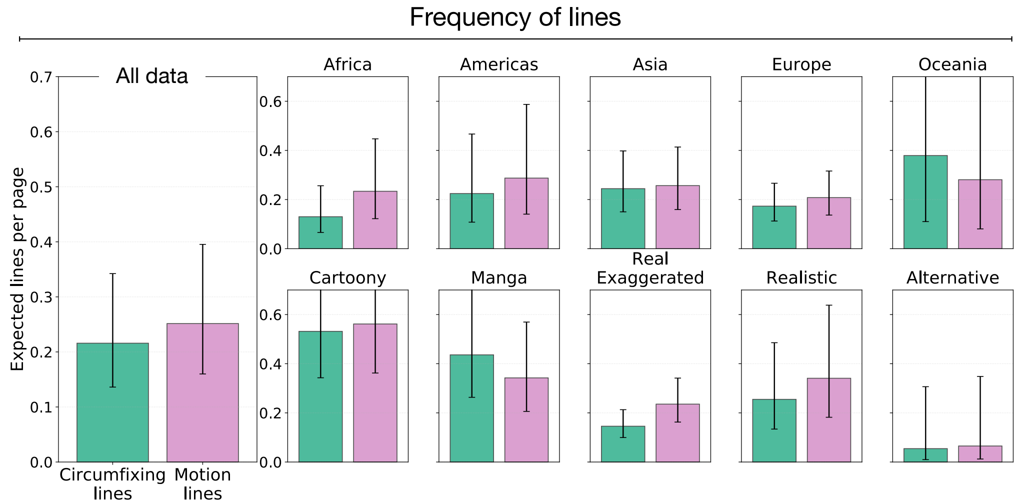

Figure 6: Frequency measured as expected number of lines per page, shown as all data and divided according to region and style. All data (left plot): Circumfixing lines: n (pages with lines) = 704, expected count per page = 0.216. Motion lines: n (pages with lines) = 928, expected count per page = 0.251.

veying less information, we expected them to also be more frequent than motion lines, but we found no difference in the frequency between the lines. We argue that the reason for this relates to the specific properties of motion semantics and requirements of visual languages in comics, which we discuss in the next paragraphs.

As established by Krajinović et al. (2025), motion lines mark directed movement. Directed movement can be defined as "a type of autonomous movement in which the agent contingently directs its movement toward (or away from) another object, state, or location" (Opfer, 2002, p. 100). It is clear that, in comics, which have character-driven events, this type of movement should be more frequent on average than unspecified and potentially aimless movement. Since a large proportion of directed movement is marked by motion lines, this would explain why motion lines have a higher frequency than what we would expect on the basis of our communicative efficiency theory alone. This higher frequency of motion lines could override the already high frequency of circumfixing lines, leading to no overall difference between the frequencies of the two types of lines. Our results on visual style contrasts further support this interpretation.

Different visual and storytelling requirements of visual styles might play a role in the frequency of circumfixing and motion lines. In the style of real exaggerated, most stereotypical of the superhero genre, motion lines were significantly more frequent than circumfixing lines, and manga displayed a non-significant trend reversal (see Results). The fact that the style of real exaggerated had more motion than circumfixing lines could be explained by the high proportion of action scenes in the superhero genre, which typically includes more directed movement and high-speed actions, both of which can be marked by motion lines. Thus, the need to depict directed movement in comics might be one of the factors modulating the frequency of motion lines. Conversely, other styles, such as manga, might have different requirements specific to their representation of motion (see Results), and/or more diverse content created in this style. This is consistent with the fact that visual style has been shown to be the domain of comics with the most variability across different dimensions of visual language structures (Cohn, 2023; Cohn, Schilperoord, & Cardoso, 2026).

While future studies on comics might test the information content of visual affixes in context, in this study we showed that, based on previous corpus studies, circumfixing lines are overall more underspecified than motion lines, and based on our analysis, that they are shorter. We interpret that as empirical support for communicative efficiency playing a role in determining the information-size relationship in the visual affixes of motion in comics.

Taken together, this study suggests that the visual affixes of motion in comics are structured in communicatively efficient ways regarding their size, as the smaller affixes are more semantically underspecified. When it comes to the frequency of visual affixes of motion, this study points to the role of visual style of comics in modulating their frequencies. Future studies will need to analyze fine-grained characteristics of visual style and motion events that might modulate the variable frequencies of circumfixing and motion lines.

on average, which cannot be independently established, circumfixing lines still convey less information about the type of movement they mark, as established by previous literature (see Introduction). Additionally, iconicity also modulates the length of at least some lexical items of spoken languages (Dingemanse et al., 2015), which are nonetheless subject to the pressures of communicative efficiency, including the hypothesized uniform information distribution. This is in line with shorter words and smaller graphics encoding less information, regardless of the exact degree of their iconicity.

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