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How uncommon is tickertaping? Prevalence and characteristics of seeing the words you hear

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Tickertape experience is the subjective phenomenon of routinely visualizing the orthographic appearance of words that one hears, speaks, or thinks, like mental subtitles in the mind's eye. It has been observed in grapheme-color synesthetes, whose letter visualizations are colored, but has been very little studied. We report a survey, among 425 Norwegian adults from varied sub-samples, of the prevalence, character, and associated skills of tickertaping. Our questionnaire was designed to reflect different degrees of automaticity of the experience. While strongly automatic tickertaping appeared rare ($n = 6$; $CI_{95} = 0.6\%$ to 3.2% of sample), lesser degrees of text visualization were reported by more than half of respondents, indicating a continuity between extreme tickertaping and normal cognition. Tickertaping was not strongly associated with greater awareness of an inner voice while reading silently. We also found no strong evidence that tickertapers are unusually likely to self-report skill in rapidly enumerating heard words, or in backward spelling and backward speaking, despite the fact that these skills have been observed in single-case studies of tickertapers. The qualitative character of tickertaping varied among respondents, and included negative experiences. However visualization of letters was predominantly uncolored, indicating that tickertaping is a phenomenon in its own right and not just a subset of grapheme-color synesthesia. We suggest tickertaping is an explicit expression of the close interconnection between phonemic and graphemic representations of words which, for reasons we do not yet understand, manifests as visual imagery with a varying degree of automaticity.

Keywords: Tickertape; Synesthesia; Tickertape synesthesia; Visual imagery; Language; Prevalence.

Some people report routinely visualizing the orthographic appearance of words that they hear, so that listening to speech induces a band of visualized text in their mind's eye. The analogy of mental subtitles is often used, and the phenomenon is now usually referred to as *tickertape* experience (e.g., Chun & Hupé, 2013). Qualitative descriptions date at least as far back as Galton (1883). More recently there have been passing references to tickertaping in the synesthesia literature and online forums, where the phenomenon has been referred to as *tickertape synesthesia* (Cytowic & Eagleman, 2009; Simner, Mayo, & Spiller, 2009) because an extra visual dimension to sensory experience is cross-modally induced by auditory input in an involuntary manner. Within this literature, tickertaping is usually described among grapheme-color synesthetes who sometimes visualize heard words in the same letter-colors that they routinely experience for read words (e.g., Simner, 2007). However, uncolored tickertaping can occur in the absence of grapheme-color synesthesia (Chun & Hupé, 2013).

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Few empirical studies of tickertaping have been conducted. Unpublished work by Linn, Hancock, Simner, and Akeroyd (2008) claimed above-average spelling, digit span, and detection of degraded speech in a group of 12 tickertapers. Price and Mykland (2013) outlined an unpublished single-case study of AM, a female tickertaper in her early twenties who vividly experiences non-colored visualized text when she hears words, speaks, or thinks verbally. For longer words, or sentences, her subtitles move right to left in imaginal space. Her tickertaping is associated with accurate and effortless enumeration of letters in long words, and of words in sentences, that was formally shown to be exceptionally fast in laboratory studies (mean RTs of $z = -3.1$ and -3.2 respectively, compared to 22 control participants). Coltheart and Glick (1974) described another case study of O, a young female with vivid non-colored word visualization who was proficient at speaking backward and showed good ability to spell whole sentences backward. Note that O was presented as an example of unusual visual imagery, rather than synesthesia. Interestingly, at least some of the proficient backward speakers whose skills are reported in popular media (e.g., YouTube) also report that this is related to effortless word visualization.

Recently, Bastiampillai, Dhillon, and Chui (2014) reported tickertaping — experienced since childhood — in an adult psychiatric patient, and speculated whether this may have been causally associated with a temporal lobe cyst diagnosed in late adolescence.

Here we present a survey of the prevalence and associated characteristics of tickertaping in a Norwegian sample of normal adults. In particular, we wished to survey tickertaping in a way that was sensitive to various grades of automaticity of the experience. While some people may tickertape in an obligatory manner whenever they hear speech, informal observation suggests others may have a less strongly automatic visualization of words, which occurs involuntarily but more occasionally. Yet others are able to vividly visualize words in a manner that is under voluntary control, such as participant O of Coltheart and Glick (1974) who had practiced her skill over many years. Thus, the more extreme examples of tickertaping may lie at one end of a continuum of individual differences in the automatization of explicit grapheme activation by phonemic input or internal word activation.

We also aimed to complement a recent prevalence estimate of the most strongly automatic tickertaping that was included in a wider survey of synesthesia and visual imagery that was completed online by 1017 respondents in a French population (Chun & Hupé, 2013). Chun and Hupé estimated strongly automatic tickertaping to occur in at least 6.9% of their sampled population. However, this estimate might be inflated for the following reasons.

First, our personal experience of strong tickertapers, such as AM from Price and Mykland (2013), suggests that word visualization is usually induced by heard words, *and* by their own speech, *and* by verbal thinking. Chun and Hupé classified respondents as tickertapers on the basis of a *yes* rather than *no* response to one of two questions. One question tapped automatic visualization induced by hearing, and the other tapped visualization induced by speaking *or* thinking. (The wording was: "*When you listen to someone speaking, do you automatically visualize the words that she/he's saying (like a 'teleprompter' in a way, that scrolls in your head)?*"; "*When you speak (or think verbally), do you automatically visualize the words you are saying?*") If tickertapers had been classified on the basis of a *yes* to both questions, prevalence would have been only 3.3% (our re-calculation based on Chun and Hupé).

Second, false positives to the binary *yes/no* questions could have been enhanced by potential ambiguity in the wording of questions. For example, word visualization could have been misinterpreted as referring to visual imagery of word semantics, rather than the orthographic appearance of words, especially in the context of other questions about visual imagery. Additionally, the rather technical concept of automaticity may not always have been understood in the intended manner.

Further aims of our study were to explore whether tickertapers typically report (1) augmented auditory imagery of the spoken sound of words that one silently reads, which could occur if tickertaping is mediated by unusually strong, and bi-directional, phoneme-grapheme co-activation; (2) the letter enumeration skills shown by AM in the case study of Price and Mykland (2013); (3) skill in backward spelling or backward speaking, as in the case study of O (Coltheart & Glick, 1974). Finally we wished to chart various qualitative aspects of tickertape experience.

METHOD

Participants and procedure

Data were collected across five diverse convenience sub-samples: Visitors to a natural history museum (MUSEUM), visitors to a film festival (CINEMA), students at a Norwegian "folk high school" for young adults (HIGH SCHOOL), members of authors' social networks (SOCIAL NETWORK), and psychology students (UNDERGRADUATES). Sub-sample characteristics are detailed in Table 1.

TABLE 1
Characteristics of the five sub-samples. From left to right: Sample (with no. people invited to take part), details of setting, response rate, sex, and age

Sample	*Setting*	*% response*	*% males*	*age range*
MUSEUM n = 168	Visitors at the Bergen Natural History Museum, approached on a Sunday near children's area. Mainly pensioners and families with children. (October 2013)	86%	46%	20–76 years M = 39.8 SD = 12.6
CINEMA n = 93	Visitors to Bergen International Film Festival, approached in partly seated foyer area while waiting to enter movie theater. (October 2013)	77%	54%	18–68 years M = 29.0 SD = 12.3
HIGH SCHOOL n = 86	Students, and a few staff, at folk high school near Bergen (Fana Folkehøgskole)*. Completed during a lunch break. (November 2013)	96%	36%	18–47 years M = 20.5 SD = 5.1
SOCIAL NETWORK n = 80	Members of authors' social networks, invited to take part via Facebook and e-mail. Invitees could not be blood relatives of each other. Distributed as pdf. file, returned by e-mail. (December 2013).	38%	35%	19–56 years M = 26.6 SD = 9.5
UNDERGRADUATE n = 200	Large lecture of introductory cognitive psychology undergraduates at University of Bergen. First given 25-minute lecture on synesthesia by author M. P., which mentioned tickertaping. Filled questionnaires during lecture break 30 minutes later. (February 2014)	85%	19%	19–36 years M = 21.1 SD = 2.3

Note: *A Norwegian Folkehøgskole is a private boarding college, for young adults, that offers a year of exam-free themed education between school and university levels.

The questionnaire was introduced as being about individual differences in language experiences. To minimize sampling bias, neither tickertaping nor synesthesia were mentioned, except for sub-sample UNDERGRADUATE (see Table 1). Depending on the questionnaire version, which differed slightly across sub-samples, completion took 5–15 minutes.

Overall response rate was 78.6%. This rises to 84.6% if we exclude the small SOCIAL NETWORK sub-sample in which participants were recruited via email rather than in person, and which had a lower rate than other sub-samples. Overall, 465/492 of returned questionnaires were complete (94.5%). Of those, we discarded returns that had been filled out using an optional English version of the survey (n = 11), and returns from participants who did not give Norwegian as their mother tongue (n = 39). This left 425 participants with 34.6% males and age range 18–76 (M = 28). All analyses derive from this subset of participants.

Procedure conformed to University of Bergen Psychology Faculty ethical guidelines.

Instrument and scoring

The questionnaire was written in Norwegian (Bokmål script) for all included participants. It first presented descriptions of "*4 types of experience that some people report.*" Experiences 1–3 were descriptions of tickertaping, induced respectively by hearing speech, speaking oneself, or thinking verbally (henceforth *hear, speak*, and *think*). Experience 1 was phrased:

> *Some people, when they **hear** somebody talking to them, also have an impression in their mind of the **written visual appearance** of the words (i.e., as if printed or handwritten), a bit like film subtitles in their head.*

For experiences 2–3, the clause "*when they **hear** somebody talking to them*" was replaced respectively by the clauses "*when they **speak out loud***" and "*when they **think to themselves in words***". After each description, participants were asked: "*Please indicate whichever one of the following statements best describes your own experience.*" Response alternatives (original bold text) were:

1. *I **almost always** have this experience, spontaneously **without even trying**.*
2. *I **sometimes** have this experience, spontaneously **without even trying**.*
3. *I **sometimes** have this experience, but it is something I **do deliberately**.*
4. *I **never** or **hardly ever** have this kind of experience.*
5. *I don't know.*

These multiple-choice response options, contrasting a range of experiences in non-technical language, were intended to minimize false positives. Responses on the first three questions were used to generate a range of prevalence estimates for tickertape experience, with differing criteria regarding (1) the degree of automaticity of visualization, and (2) the number of inducers triggering the experience. We stipulatively define participants who selected response 1, for all three inducers, as *obligatory* tickertapers; these participants show the strongest degree of automaticity and conform to our strictest criterion for tickertaping. A lesser degree of automaticity is shown by participants selecting responses 1 or 2 for all inducers, who are labeled *involuntary* tickertapers. Those selecting response 3 for all inducers are labeled *voluntary* tickertapers. Participants selecting responses 1 or 2 for at least one inducer are labeled *involuntary × 1*. Those selecting responses 1, 2, or 3 for at least one inducer are labeled *any × 1*. Note that categories overlap; e.g., *obligatory* is a subset of *involuntary*.

Experience 4, which used the same response alternatives, described hearing the sounds of the words one is reading:

> *Some people, when they **read to themselves** without speaking, also have an impression in their mind of the **sound** of the words being spoken.*

Participants next indicated whether their daily experience included rapid enumeration of letters in heard words, or exceptional abilities for backward spelling and backward speaking. Response alternatives were *Disagree, Unsure*, and *Agree*. For samples MUSEUM, CINEMA, and HIGH SCHOOL, questions were:

1. *When I **hear** a word being spoken, I feel that without trying I almost instantly know how many letters there are in the word.*
2. *When I **hear** a word being spoken, I can impress your friends with my unusually good ability to **spell** the word out loud **backward**.*
3. *When I **hear** a word being spoken, I can impress my friends with my unusually good ability to **say** the word **backward**.*

For sub-samples SOCIAL NETWORK and UNDERGRADUATE we rephrased question 1 because we were suspicious of very high rates of *Agree* responses shown in preceding sub-samples. Precision of wording was improved to:

> *1. When I **hear** a word being spoken, then even if it is a long word like "interesting" I instantly know exactly how many letters there are in the word. I can do this very fast, and correctly, without writing down the word or counting on my fingers. I just "know" what the correct answer is.*

For sub-samples SOCIAL NETWORK and UNDERGRADUATE (n = 184), who filled out questionnaires under lesser time pressure, we included 14 additional questions about the qualitative characteristics of tickertape experience. Participants were instructed to only answer if they experienced visualization for at least one type of inducer. Questions asked about characteristics such as color, movement, font, age of onset, etc., as well as advantages and nuisances associated with the experience. One item, which asked whether or not the experience of visualized words felt projected outside the body, was inspired by the projector-associator distinction within synesthesia research and by previous observations from single-case studies that tickertapers may either report seeing the letters in imaginal space (i.e., associators, such as AM reported by Price & Mykland, 2013) or projected into extrapersonal space (i.e., projectors, such as O reported by Coltheart & Glick, 1974). For this item, written descriptions were complemented by cartoons, following Skelton, Casimir, and Mohr (2009) who suggested that self-report measures of the projector-associator distinction are more reliable if based on illustrations rather than purely verbal statements. Age, sex, mother tongue, and educational level were recorded at the end of the questionnaire.

Effect sizes for any formal comparisons between prevalence values are expressed in terms of risk ratios (*RR*; prevalence A/prevalence B). These are stated with 95% confidence intervals (CI_{95}), and were computed from 2 × 2 contingency tables using online software (http://vassarstats.net). The latter site was also used to compute CI_{95} on observed proportions, using the recommended method of the Wilson score interval with continuity correction applied (Newcombe, 1998).

RESULTS

Prevalence estimates for visualized words

Figure 1a illustrates the range of obtained estimates as criteria for tickertaping are progressively relaxed. Only 1.4% of participants (n = 6; CI_{95} [0.6, 3.2]) met our strictest criterion of *obligatory* word visualization for all three inducers (2 male, ages 21, 21, 22, 52, 67, and 68). Most came from the largest sub-samples (three from MUSEUM, two from UNDERGRADUATE, and one from HIGH

SCHOOL). The weaker criterion for *involuntary* tickertaping was met by 8.7% of participants (n = 37; CI_{95} [6.3, 11.9]). *Voluntary* tickertaping was reported by 4.7% of participants (n = 20; 95% CI_{95} [3.0, 7.3]).

The criterion of *involuntary* × *1* was met by 29.2% of participants (n = 124; CI_{95} [25.0, 33.8]). Higher frequency of participants in this category permitted formal comparison between our five sub-samples, which did not indicate reliable differences [Pearson $\chi^2(4) = 4.22$, $p = .38$]. Our most lenient criterion of *any* × *1* was met by 53.4% of participants (n = 227; CI_{95} [48.5, 58.2]), again without reliable differences between sub-samples [$\chi^2(4) = 4.21$, $p = .38$]. In other words, over half the overall sample report some degree of word visualization.

Finally, the proportion of participants who chose response option, "*I **never** or **hardly ever** have this kind of experience*," for all inducers, was 43.3%, (n = 184; CI_{95} [38.6, 48.2]). An almost complete lack of word visualization is therefore less common than at least some degree of word visualization.

No support was found for a relationship between prevalence of word visualization and either age, sex, or educational level (secondary school vs. tertiary education) (data not shown). A null effect of sex was also reported by Chun and Hupé (2013).

Comparison between different inducers

Pooling over the *obligatory, involuntary* and *voluntary* response categories, relative prevalence of reported visualization for the *hear* versus *speak* versus *think* inducers was 1.0/1.0/1.4. The *think* inducer (CI_{95} [0.40, 0.50]) was reliably more common than for *hear* (CI_{95} [0.29, 0.38]) or *speak* (CI_{95} [0.28, 0.37]). A similar trend was apparent for *obligatory* visualization on its own (1.0/.6/1.8), though not reliable given the small n.

Visualization for *think* was also more likely to occur in isolation, without visualization for other inducers: The conditional probability of reporting visualization for only *think* showed a CI_{95} [0.23, 0.36] that does not overlap the CI_{95} for *hear* [0.07, 0.19] or *speak* [0.01, 0.09]. In addition, visualization for *think* was less likely to predict visualization for all three inducers: The conditional probability that *think* visualizers will visualize for all inducers shows a CI_{95} [0.41, 0.55] that does not quite overlap the equivalent CI for *hear* [0.56, 0.72] or *speak* [0.58, 0.74].

In sum, compared to *hear* or *speak* inducers, the *think* inducer is less diagnostic of a generalized tendency to tickertape for all verbal material.

Prevalence of hearing the words you read

Auditory imagery of the sounds of silently read words was a common experience, as expected from the extensive literature on subvocalization during reading (Leinenger, 2014). Using similar scoring criteria as for visualized words, 62.1% of participants reported auditory imagery to be *obligatory*, 17.6% reported it as *involuntary*, and 10.8% as *voluntary* (90.6% in total). Only 8.2% claimed no experience at all. This is strikingly opposite to the response pattern for visualized words, where 1.4% of participants claimed *obligatory* visualization and 43.3% claimed no word visualization at all (see Figure 1b).

We next examine whether auditory imagery for read words was greater for people who tend to visualize heard words. Among participants who claimed *obligatory* word visualization for all three inducer types, all six claimed to experience the sound of read words to some extent (four obligatory, one involuntary, one voluntary). Despite this, *obligatory* auditory imagery was not actually more common among these six participants (66.7%, 4/6) than among remaining participants (62.1%; 260/419) [tickertapers/others RR = 1.07, CI_{95} [0.61, 1.90], Fisher exact p(2-tailed) = 1.00]. Similarly, participants who claimed *some* degree of word visualization (whether involuntary or voluntary) for at least one inducer were no more likely to claim *some* degree of auditory imagery experience for read words (90.3%, 205/227) than were other participants (90.9%; 180/198) [RR = .99, CI_{95} [0.93, 1.06], $\chi^2(1) = 0.04$, $p = .84$].

If we focus specifically on participants who reported *obligatory* visualization for *heard* words — which could be considered the opposite of auditory imagery for read words — a weak trend for an association is found. Of these participants, 85.7% (12/14) heard the words they read in an obligatory manner, compared with 61.3% (252/411) of remaining participants [visualizer/non-visualizer RR = 1.40, CI_{95} [1.11, 1.75], $\chi^2(1) = 3.43$, p(2-tailed) = .06]. However, of participants who claimed any degree of visualization for *heard* words, 94.3% (133/141) reported *some* degree of sound experience for read words, compared to 88.7% (252/284) of other participants; this comparison has a negligible effect size [RR = 1.06, CI_{95} [1.00, 1.13], $\chi^2(1) = 3.46$, p(2-tailed) = .06].

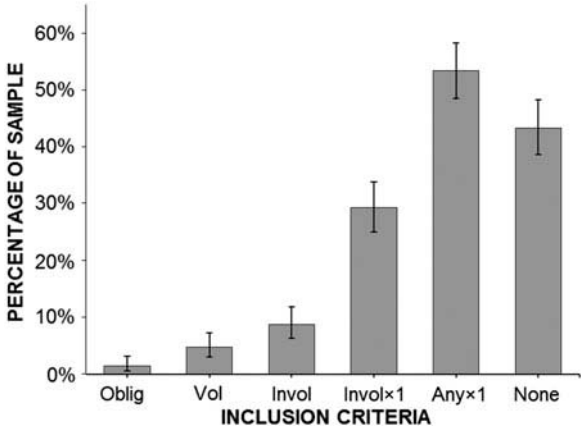

Figure 1a. Proportion of sample reporting (a) obligatory word visualization for all three inducers (Oblig); (b) voluntary visualization for all three inducers (Vol); (c) involuntary visualization for all three inducers (Invol); (d) involuntary visualization for at least one inducer (Invol × 1); (e) obligatory, involuntary or voluntary visualization for at least one inducer (Any × 1); (f) no visualization at all (None). Errors bars are CI_{95}.

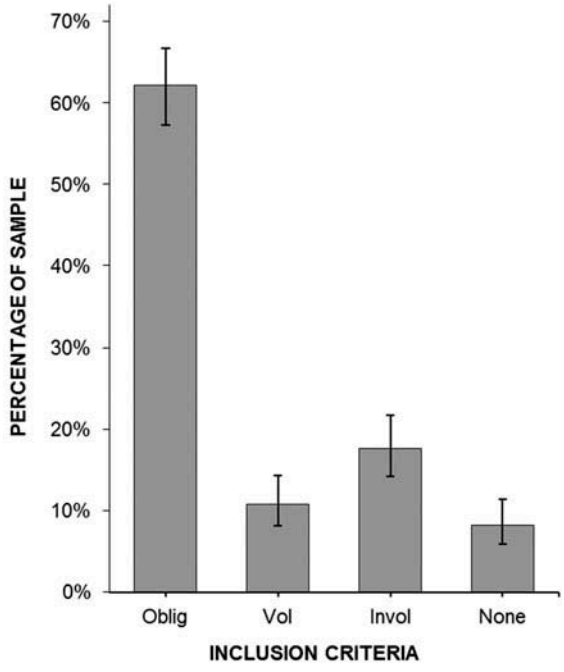

Figure 1b. Proportion of sample reporting (a) obligatory auditory imagery when silent reading (Oblig); (b) voluntary auditory imagery when silent reading (Vol); (c) involuntary auditory imagery when silent reading (Invol); (d) no auditory imagery when silent reading (None). Errors bars are CI_{95}.

Letter counting, backspelling, and backspeaking

For the first version of the letter counting question, received by 243 participants, *agree* responses for experiencing this skill were reported by 75% of obligatory tickertapers (3/4) compared to 17% of remaining participants (40/239) [Fisher exact, p(2-tailed) = .02]. However, the substantial prevalence among non-tickertapers suggested the question had been ambiguously phrased. This is supported by the fact that 26% of participants (n = 63) responded that they were *unsure*. For the rewritten question, received by 182 participants, only 4% responded *unsure* (n = 8, including one *involuntary* tickertaper), and the only person to respond *agree* was not among the 2 *obligatory*, 12 *involuntary*, or 9 *voluntary* tickertapers.

Agree responses to backspelling and backspeaking skills were respectively reported by 5% (n = 20) and 4% (n = 18) of the total sample (of whom 13 reported both skills). Table 2 (part a) compares reported prevalences of a variety of tickertape categories against participants who report neither *obligatory*, *involuntary*, nor *voluntary* tickertaping (henceforth *non-tickertapers*). None of our 6 *obligatory* tickertapers, or 20 *voluntary* tickertapers gave *agree* responses. For *involuntary* word visualization, prevalence of backspelling among these participants rises to 11%, and backspeaking to 8%. Although these prevalences give risk ratios of over 2.0 when compared to *non-tickertapers*, they are not reliably higher (i.e., ratios of 1.0 lie within the CI_{95}, and p-values for 2 × 2 tables are non-significant; Fisher exact, both ≥ .10). Comparisons were repeated after combining *agree* responses with *unsure* responses, which were given by 10% and 9% of participants for backspelling and backspeaking respectively (see Table 2, part b). Some trends are now apparent for higher prevalence among tickertapers, although it is only for backspelling that risk ratios are reliably above 1.0, and then only prior to correction for multiple testing.

In summary, the majority of *obligatory, involuntary* and *voluntary* tickertapers clearly do *not* describe themselves as skilled in any of the three tasks. When strict criteria are applied, we also find no evidence that prevalence of self-reported skill is higher than usual among tickertapers. With looser criteria we nevertheless observe a tentative trend for higher prevalence of backspelling, and to lesser extent backspeaking (though not for *voluntary* tickertapers). At observed prevalence levels, larger sample size would be needed to confirm these trends with statistical reliability.

Further characteristics

Sub-samples SOCIAL NETWORK and UNDERGRADUATE received additional questions

TABLE 2
Prevalence of self-reported backspelling and backspeaking skill, compared between non-tickertapers (Non TT) and three categories of tickertapers (TT; Oblig = obligatory, Invol = involuntary, Vol = voluntary). Prevalences are presented separately for (a) agree responses and (b) combined agree and unsure responses

	Prevalence		*TT vs. Non TT prevalence*	
	%	*n*	*p*	*RR (CI_{95})*
(a) Agree				
Backspelling	4.7%	(20/425)		
Oblig	0%	(0/6)	–	–
Invol	10.8%	(4/37)	.10	2.49 (0.88, 7.05)
Vol	0%	(0/20)	–	–
Non TT	4.3%	(16/368)		
Backspeaking	4.2%	(18/425)		
Oblig	0%	(0/6)	–	–
Invol	8.1%	(3/37)	.39	2.06 (0.60, 6.56)
Vol	0%	(0/20)	–	–
Non TT	4.1%	(15/368)		
(b) Agree/unsure				
Backspelling	15%	(64/425)		
Oblig	50%	(3/6)	.04	3.68 (1.59, 8.53)
Invol	29.7%	(11/37)	.01	2.19 (1.25, 3.82)
Vol	15.0%	(3/20)	1.0	1.10 (0.38, 3.23)
Non TT	13.6%	(50/368)		
Backspeaking	13.6%	(58/425)		
Oblig	33.3%	(2/6)	.18	2.61 (0.82, 8.35)
Invol	21.6%	(8/37)	.20	1.70 (0.87, 3.31)
Vol	15%	(3/20)	1.0	1.17 (0.40, 3.45)
Non TT	12.8%	(47/368)		

Note: RR is risk ratio where TT is divided by non-TT; *p* values (Fisher Exact) are 2-tailed.

about qualitative aspects of their word visualization. Of 94 qualifying participants — i.e., those with some degree of visualization for at least one inducer — 69% complied with the invitation to answer the questions (n = 65). This included all 12 participants reporting *obligatory* or *involuntar*y tickertaping, 8/9 *voluntary* tickertapers, and 30/34 other participants who visualized involuntarily for at least one inducer. High compliance to fill out the extra questions suggests these groups had salient experiences of word visualization which they considered natural to report in more detail. By contrast, the questions were answered by only 38% (15/39) of the remainder of qualifying participants; i.e., many participants who claimed to visualize voluntarily for one or two inducers did not see fit to describe their experience in more detail. This is unlikely due to unclear instructions, given high compliance by other categories of participant, and the fact that only one non-complying participant filled out the extra questions. It could suggest that this least conservative category included many false positives, or at least that experiences were not very vivid. It also supports the value of identifying strong tickertapers on the basis of tickertaping for more than one inducer.

Table 3 summarizes responses among *obligatory, involuntary*, or *voluntary* tickertapers, for all of whom the following patterns are apparent.

1. Several aspects of the experience differed between people, and sometimes within a person. This applies to whether visualized words are experienced to move, whether the words are visualized in print or as hand written, whether the person experiences motor imagery of writing the words, and to perceived detail of the imaged letters.
2. Visualized words were predominantly uncolored, indicating that the tickertape experience is not primarily a subdivision of colored-word synesthesias.
3. Although most people reported the words as "in their head," a minority claimed projected imagery, or imagery that is sometimes projected. The rarity of *unsure* responses for this controversial projector-associator distinction suggests the use of diagrams was successful in conveying the question (Skelton et al., 2009).

TABLE 3

Summary of qualitative character of word visualization for *obligatory* (Oblig), *involuntary* (Invol), and *voluntary* (Vol) tickertapers. Note that results for *involuntary* tickertapers do not include participants already listed under *obligatory* tickertapers. All questions prompted participants to choose between two opposing descriptions of their experience (e.g., "colored" vs. "uncolored"), along with an alternative option to indicate they were unsure or, where appropriate, that the experience varied. An example question is: "When you have a mental experience of the written form of a word that you hear, and/or speak, and/or think, do you experience the written word as colored or uncolored (e.g., black and white)?"

Question	*Yes*	*No*	*Varies*	*Unsure*
Color?				
Oblig	0	2	0	0
Vol	0	6	2	0
Invol	0	9	0	1
Moving letters?				
Oblig	0	2	0	0
Vol	1	2	2	3
Invol	2	3	2	3
Motor imagery of hand writing?				
Oblig	0	1	0	1
Vol	2	3	1	2
Invol	0	5	4	1
Visualization is useful?				
Oblig	1	0	–	1
Vol	8	0	–	0
Invol	8	0	–	2
Annoying/disadvantageous?				
Oblig	0	2	–	0
Vol	0	6	–	2
Invol	4	6	–	0
Multiple conversations confusing?				
Oblig	0	1	–	1
Vol	1	6	–	1
Invol	3	5	–	2
Occurs for other languages?				
Oblig	2	0	–	0
Vol	5	0	–	3
Invol	10	0	–	0
Recall onset of experience?				
Oblig	0	2	–	–
Vol	0	8	–	–
Invol	1	9	–	–
Experienced since early childhood?				
Oblig	0	0	–	2
Vol	3	1	–	4
Invol	2	3	–	5
Engage in mental word play?				
Oblig	0	2	–	0
Vol	3	5	–	0
Invol	2	7	–	1
Gives visual interference?				
Oblig	0	2	–	0
Vol	1	5	–	2
Invol	1	7	–	2
Written style?	Hand	Print	Varies	Unsure
Oblig	0	1	1	0
Vol	2	2	1	3
Invol	3	5	1	1
Projection?	"In head"	Projected	Varies	Unsure
Oblig	1	0	1	0
Vol	6	1	0	1
Invol	7	2	1	0
Level of visualized detail?	General	Detailed	Varies	Unsure
Oblig	0	1	1	0
Vol	3	3	1	1
Invol	6	2	2	0

4. Nearly all reported the experience occurs for other languages than their native tongue, with the remainder unsure.
5. Most could not recall when the experience started. Unsurprisingly, therefore, only a minority could confirm an onset in childhood. One *obligatory* tickertaper reported starting to visualize subtitles during verbal thought after seeing a film with subtitles in junior school. One *involuntary* tickertaper recalled mentally writing words before physically writing them during tests in junior school.
6. Mental word-play was only reported by a minority, and is therefore unlikely to be a developmental precursor of word visualization for the majority of tickertapers.
7. Almost all rated the imagery as useful. However a minority also claimed it could be annoying or disadvantageous. Four participants indicated that word visualization during multiple conversations can become confusing, and two even claimed that their word imagery interferes with visual perception.

GENERAL DISCUSSION

In our sample of Norwegian adults, the proportion who report involuntarily visualizing the orthographic appearance of words whenever they are heard, spoken by oneself, and activated during silent verbal thought, lies within a CI_{95} of 0.6% to 3.2% (point estimate 1.4%). These *obligatory* visualizers can be considered as the most strongly automatic variety of tickertaper. The estimate is based on a diverse sample with wide age range and high response rate.

Our estimate is less than the 6.9% minimum prevalence (CI_{95} [6.2%, 7.7%]) suggested by Chun and Hupé (2013) for automatic tickertapers in a French sample. However, differences in the manner that prevalences were estimated make direct comparison problematic. First, our estimate is based on reported visualization for a conjunction of *hear, speak* and *think* inducers, which reduces the risk of spurious false positives and corresponds to the experience of previous tickertapers we have interviewed (Price & Mykland, 2013). By contrast, the French study used the criterion of visualization for the *hear* inducer (based on one question) and/or a combination of either *speak* or *think* inducers (based on a second question). Rescoring the French data to estimate the conjunction of *hear* and *speak/think* inducers gives an estimate of 3.3% (CI_{95} [2.7%, 3.9%]) which overlaps both (1) our own original estimate (CI_{95} [0.6%, 3.2%]), and (2) our data when rescored as the same conjunction of obligatory visualization for both the *hear* inducer and the combined *speak/think* inducer (n = 7/425; CI_{95} [0.7%, 3.5%]). This overlap is nevertheless academic because estimates differed in a second respect. Whereas our prevalence rate is expressed as a percentage of *completed* questionnaires, in a study with high response rate, the French prevalence rate was expressed as a percentage of *distributed* questionnaires (n = 3743) rather than of actual respondents (n = 1017). Chun and Hupé were attempting to provide a conservative lower estimate and so assumed any synesthetes would be likely to complete the questionnaire. However, given their response rate of only 27%, their prevalence estimate would be considerably underestimated if this assumption is even partly wrong. In sum, we cannot tell whether estimate differences (or similarities) arise from differences in questions, scoring, assumptions about compliance rate for synesthetes, or language groups.

It is also difficult to know whether the French estimate includes people with tickertaping that is less obligatory. By contrast, the format of response alternatives in our own study allowed us to distinguish shades of automaticity. We separately estimated a higher 8.7% prevalence when including people who tickertape for all three inducers, in a manner that is still felt to be *involuntary*, but can be more occasional and is perhaps context-specific. We additionally identified a group of 4.7% of participants who report tickertaping *voluntarily* for all inducers, as for participant O studied by Coltheart and Glick (1974). However, despite differences in automaticity, variation in the other qualitative characteristics of the visualizations reported by *obligatory, involuntary* and *voluntary* tickertapers showed similar ranges (Table 3). This suggests that as the experience becomes progressively more automatic, underlying processes of word visualization remain continuous with those of voluntary imagery.

As criteria for tickertaping are relaxed yet further, to encompass people with at least occasional visualization to at least one inducer, the proportion of visualizers grows to exceed the proportion of people claiming visualization to be very rare or non-existent. Obviously the potential for false positives will increase as criteria are relaxed. This is supported by the fact that people reporting voluntary visualization for only 1–2 inducers often chose not to fill out the additional questions about their experience. Nevertheless, weaker tickertapers form part of a graded continuity of experience. This

extends from obligatory tickertaping and exceptionally vivid voluntary tickertaping, through diffuse varieties of weak tickertaping, to the kind of vague visualization of short single words that probably most of us can conjure in our mind with some effort. Note that claimed visualization was most frequent for the *think* inducer, which was also least predictive of tickertaping to other inducers. It is therefore suboptimal to confound responses to *think* versus other inducers, for example as in the survey of Chun and Hupé (2013).

One concern is that demand characteristics could have inflated prevalence estimates for all our categories of self-reported tickertape experience. For this reason, convergent behavioral tests have been important for establishing prevalence estimates in, for example, research on grapheme-color synesthesia (Simner et al., 2006). Unfortunately, a behavioral marker for tickertaping has not yet been developed. We think it however unlikely that a generalized demand characteristic significantly contaminated our current data. Tickertapers did not show elevated self-report of auditory imagery to read words, or letter enumeration, or backward spelling and speaking. They also complied with instructions to report their experiences in more detail and described experiences that are consistent with previous case studies.

As tickertaping was reported to be largely uncolored, it is not primarily a subset of grapheme-color synesthesia. It appears to be a phenomenon in its own right, although when co-occurring with grapheme-color synesthesia it will nevertheless influence the manner in which synesthetic color associations are experienced. Perhaps, as already suggested by Chun and Hupé (2013), tickertaping should not then be regarded as a variety of synesthesia at all. First, highly automatized and vivid tickertaping is part of a graded spectrum of word visualization that shows strong continuity with normal cognition. Second, the additional concurrent experience (visualization) is not an idiosyncratic pairing but derives from knowledge of letter form that is shared by all literates. Using similar grounds, Rothen and Meier (2013) recently rejected so-called mirror-touch phenomena as an exemplar of a true synesthesia.

It is parsimonious to suggest that the gradation in the automaticity and/or vividness of tickertaping involves some exaggeration of the normal and tight interconnection between phonological and graphemic representation of words in our mental lexicon. It is well established that *grapheme-to-phoneme* activation (grapho-phonological conversion) is crucial to reading (Rayner, Pollatsek, Ashby, & Clifton, 2011), and this manifests as the commonly experienced subjective "inner voice" of sub-vocalization during reading (Leinenger, 2014). Consistent with this, around 90% of our respondents claimed auditory imagery of the sound of silently read words. Development of this grapheme-phoneme mapping during reading acquisition may rely on enhanced connectivity between cortical areas involved in phonological processing and areas involved in visual and orthographic processing, such as the proposed visual word form area (VWFA) in the left lateral occipitotemporal sulcus (Perrone-Bertolotti et al., 2014). There is also some evidence that *phoneme-to-grapheme* activation is important. At the behavioral level, word spelling has an influence on auditory perception (Ziegler and Ferrand, 1998). At the neural level, literates show top-down activation of the VWFA during auditory speech processing (Dehaene et al., 2010). Exaggeration of such activation could potentially mediate the orthographic visualization of words that are heard, vocalized, or sub-vocalized, and exemplify how visual imagery generally involves activation of visual representations in occipitotemporal areas (Cichy, Heinzle, & Haynes, 2012; McNorgan, 2012).

Although our data provided no strong support that routine sub-vocalization was more explicit among tickertapers, a trend was detected specifically for an association between obligatory tickertaping to *heard* words and obligatory auditory imagery. The question of whether exaggerated phoneme-grapheme activation in tickertapers is bi-directional therefore remains open. It also remains unanswered *why* phoneme-to-grapheme activation would become exaggerated and more explicit among some people. At present, we do not know whether the crucial individual differences lie within language processing, visual imagery, or some interaction between the two. Speculatively, tickertaping may arise from an interaction between high phonological awareness and disposition for vivid visual imagery.

Our study provisionally suggests that the unusual skills documented in some case studies of word visualizers are atypical of tickertapers generally. Self-reports of the letter enumeration skill shown for AM (Price & Mykland, 2013) were vanishingly rare, even among the strongest tickertapers, once questionnaire wording was improved. Backward spelling and speaking skills, as illustrated by O (Coltheart & Glick, 1974) and demonstrated in social media, were also not convincingly more reported among tickertapers. Caution is warranted here as our data are based on self-report. Although both AM and O were aware of their unusual abilities prior to formal testing, and self-awareness of

backward spelling/speaking is demonstrated on social media, behavioral testing could reveal that many tickertapers have these skills but are unaware of them. More likely, tickertapers have an advantage in acquiring such skills, but these skills nevertheless require considerable practice.

Convergent with Chun and Hupé (2013), many qualitative aspects of tickertapers' experience showed considerable variability, for example in whether handwritten or printed font was experienced, or whether the visualized words were felt to move. Notably, some experiences varied within individuals, suggesting similar flexibility of visual expression as found during more normal visual imagery. The reported sensation of one's hand writing the visualized text indicates that motor as well as visual imagery is involved for some tickertapers; this experience, which we have encountered previously during interviews with tickertapers, has not to our knowledge been reported before. Characteristics expressed by the majority of tickertapers included visualizing words in other languages (although Chun and Hupé reported some tickertapers who did not do this), not recalling the onset of the experience, and experiencing text in imaginal rather than projected space (although a minority reported projection like Coltheart and Glick's single-case, 1974).

While most reported the visualization as advantageous, some claimed confusing parallel visualization during parallel streams of speech. This has been reported by the psychiatric tickertaper of Bastiampillai et al. (2014), and also by AM (personal observation). Reports of interference between word imagery and visual perception are consistent with previous reports by O. These negative aspects of tickertaping clearly require further investigation.

In conclusion, we suggest tickertaping should not be regarded as a curious abnormality, but as an explicit expression of phoneme-grapheme activation that manifests as visual imagery with a varying degree of automaticity. Future work should establish the behavioral and neural correlates of tickertaping, and its potential contribution to understanding normal processes of imagery and language processing.

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