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RESEARCH ARTICLE

Grain levels in English path curvature descriptions and accompanying iconic gestures

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Abstract: This paper confirms that the English verb system (similar to the Finnish, Dutch, and Bulgarian verb systems [17, 22]) represents path curvature at three different grain levels: neutral path curvature, global path curvature, and local path curvature. We show that the three-grain-level hypothesis makes it possible to formulate constraints on English sentence structure and makes it possible to define constructions in English that refer to path curvature. We furthermore demonstrate in an experiment that the proposed English lexicalization pattern regarding path curvature in tandem with the spatial information shown to English speakers correctly predicts their packaging of grain levels in iconic gestures. We conclude that the data studied confirm Nikanne and Van der Zee's [22] three-grain-level hypothesis in relation to English and Kita and Özyürek's [11] interface hypothesis in relation to gesture production.

Keywords: curvature, English language, gesture production, grain level, verb semantics, motion event, path representation, scale, spatial resolution, speech production

1 Introduction

The encoding of spatial information at different levels of spatial resolution is an important issue in spatial information science. For example, it has been observed that scale change in spatial representations has an impact on people's accuracy for judging place locations and path orientations, that scale change has an impact on our memory for spatial locations, and that scale change impacts on our use of reference frames [16, 19, 26]. Research in spatial language has, in addition, offered insights in how it is possible for human beings to communicate about spatial information at different levels of granularity. Research in this area has shown, for example, that landmark size and object distribution—as scale setting means—have an influence on the use of *near* and *far* when describing object location [3, 5, 30]. Relatively little has been published, however, on the way in which languages encode paths at different grain levels, although Nikanne and Van der Zee [22] have reported on grain level encoding for paths in Finnish and Dutch, Martinez has reported on Bulgarian [17], and Schmidtke [25] on German. In this paper we for the first time look at the way in which paths are represented at different levels of spatial resolution in English.

Path descriptions have been studied extensively in spatial language research. Research in spatial language has focused, for example, on the relation between path versus manner of motion encoding [27, 28]; path starting point versus path end-point encoding [14, 15]; the way in which spatial features underlying path descriptions—such as boundedness—constrain grammatical encoding [2, 20]; and how language represents path shape [29]. However, in order to fully understand the way in which human beings convey information about path structure also gestures have been studied. For example, Kita and Özyürek [11] have shown that the gestures people make when talking about a moving Figure are influenced by the language that is spoken and the shape of the path that is perceived. The different grain levels at which paths can be represented have, however, so far not been studied in relation to gesture. For this reason we not only focus here on how English speakers encode paths at different levels of spatial resolution in their language, but also how these speakers encode paths at different grain levels in the gestures that accompany their speech. More specially, we focus on how path curvature is encoded at different grain levels in the English language and in gesture.

Example (1) illustrates what we mean by path curvature encoding at different grain levels:

(1) *The skier slalomed down the mountain*.

(1) shows that it is possible to convey in a single sentence in English the global direction of a moving Figure (the skier) in relation to a Ground object (the mountain), and the more fine grained representation of a slalom-like shape of the path of the Figure. When we refer to grain levels in this paper we refer to the levels of spatial resolution at which path curvature is described in single sentences, such as (1).

One aim of our paper is to present some ideas on how English encodes path curvature at different grain levels when using verbs or when using so-called constructions [8]. A second aim is to show how grain level encoding of path curvature in English is linked to grain level representation in iconic gestures that people spontaneously make when they talk [18]. Sections 1–4 focus on our first aim, while Section 5 addresses the second aim. Section 6 summarizes how the interaction between language and gesture allows English speakers to convey observed path curvature at different grain levels in a single communicative act.

2 Grain levels in English path curvature descriptions

Throughout this paper we will use Nikanne and Van der Zee's [22] three-grain-level hypothesis to distinguish between three levels of spatial resolution at which motion verbs are assumed to represent path curvature:

(2) Grain level 0 verbs (neutral path curvature specification): e.g., *to approach, to arrive, to come, to depart, to go, to leave, to move, to travel, to tour*
Grain level 1 verbs (global path curvature specification): e.g., *to arc, to curve*
Grain level 2 verbs (local path curvature specification): e.g., *to slalom*, *to spiral*, *to wind, to zigzag*

Motion verbs describing path curvature in (2) must be distinguished from motion verbs describing object axis curvature changes [29]:

(3) *to arch*, *to bend*, *to coil*, *to fold*, *to kink*, *to straighten*, *to twist*, etc.

The verbs in (3) describe changes in the curvature of objects, bodies, their parts, etc.

Many English verbs, however, straddle both categories:

(4) *The ball <u>curved</u> into the net* (*PATH*—the ball moved with a curve in its path).
(5) *Ben's back <u>curved</u> when he tried to negotiate the slide* (*BODY*—Ben's back curved).
(6) *Zoë <u>slalomed</u> down the hill* (*PATH*—Zoë moved with curves in her path).
(7) *The path <u>slaloms</u> down the mountain* (*OBJECT*—the path has curves in it).

Furthermore, some English verbs in (3)—but not all—can be coerced [24] into describing path curvature:

(8) *Peter straightened the car after he almost got off the road*.
(9) * *He folded into the alley*.[1]

Some manner of motion (MoM) verbs such as *to wriggle*, *to rock*, *to roll*, and *to swing* can also be coerced into describing path curvature:

(10) *The snake wriggled to the door*.

However, the semantic structures of MoM verbs do not express the shape of a path. They refer to the movements of the object causing and/or undergoing the motion which in turn allows for the pragmatic inference that the path has a distinctive curvature (it is our knowledge about the way in which wriggling snakes move that allows us to infer that the path in 10 has curves in it). Nikanne and van der Zee [22] describe the mechanism that allows manner of motion verbs to describe path curvature.

In this paper the primary focus is on the path curvature verbs described in (2), while we may include verbs that straddle both the path curvature and object curvature categories described in (3). We will not, however, focus on situations in which motion verbs or MoM verbs can be coerced into expressing path curvature.

Let us start by considering each of the grain levels for encoding path curvature in more detail. Grain level 0 verbs (hereafter GL0 verbs), such as *to come* and *to go*, do not make any reference to the shape of a path; they just express that a Figure is moving from one place to another:

(11) *The camel went from the tree to the water well.*

[1]We will indicate sentences that are not acceptable from a syntactic or semantic perspective with a "*" in front of them

Although we are likely to assume that the global path described in (11) is straight by default, the path could be of any shape—curved, straight, or even zigzag-like. As GL0 verbs do not restrict the shape of a path, we say that these verbs express *neutral path curvature*. Since neutral path curvature is the limiting case of specifying detail (i.e., no detail of path shape at all) we assign neutral path its own grain level.

Grain level 1 verbs (hereafter GL1 verbs) specify the overall shape of a path of motion; they refer to a single global curvature change in a path:

(12) *The ball curved into the net*.

The verb *to curve* here indicates that the Figure follows a path whose overall shape is one smooth curve. The Figure may or may not also make smaller curves (e.g., the ball may wobble from side to side); as long as the global shape of the path can be interpreted as a curve we can use *to curve*. We say that GL1 verbs express *global path curvature*.

The GL1 verbs in English only seem to refer to smooth path curvature. This is in contrast to, for example, Dutch, where GL1 verbs distinguish between smooth and non-smooth path curvatures. Whereas *af/inbuigen* ("to bend off to/into") refers to a smoothly curved path, *af/inslaan* ("to hit off to/into") seems to refer to a more abrupt, non-smooth path shape, and *af/indraaien* ("to turn off to/into") seems to be neutral in relation to the smoothness of the path. In contrast to Dutch, English GL1 verbs are thus only specified by the feature "smooth."

Grain level 2 verbs (hereafter GL2 verbs) refer to small details of path curvature; they refer to multiple local curvature changes in a path:

(13) *The car zigzagged through the parking lot*.

In (13) the verb *to zigzag* indicates that the path consists of several iterations of angular path shapes. Unlike GL1 verbs, GL2 verbs do not make any statement about global path shape. The global path may be curved in any possible way, or it may even be straight (see Figure 1). We say that GL2 verbs express *local path curvature*.

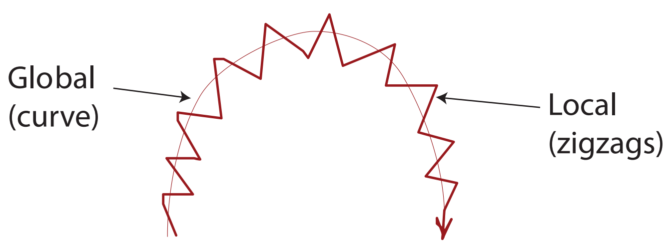

Figure 1: A combination of zigzags (giving rise to the use of the verb *to zigzag*) and a more global curve (which is not specified by the semantic structure of this verb).

To zigzag refers to non-smooth curvature changes, whereas *to slalom*, *to spiral*, *to surround*, and *to wind* refer to smooth curvatures. In contrast to English GL1 verbs, English GL2 verbs thus make a distinction between non-smooth and smooth path shape curvatures.

There are verbs that—depending on the semantic nature of the other words in a sentence—can express either global or local path curvature:

(14) *The road circled the city* (one circle; expression of global path curvature)
(15) *The plane circled above the city* (multiple circles; expression of local path curvature).

Although certain verbs are either GL1 or GL2 verbs (see 2 above), (14) and (15) show that some other verbs may straddle both categories. In this paper we will focus on verbs that can be clearly assigned to either encoding local or global path curvature.

As in Dutch and Finnish, there are no GL1 or GL2 verbs in English that explicitly specify the straightness of a global or local path. Path straightness at a global grain level is pragmatically or cognitively inferred from GL0 verbs or MoM verbs in combination with a prepositional phrase (PP) as in, for example, *The horse went/walked* [$_{\text{PP}}$ *to the tree*]. Further, as argued by Nikanne and van der Zee [22] verbs specifying straightness at a local grain level are impossible since such verbs would not be able to select an identifiable path part as their referent (at every level of detail path parts contain straight elements, even a slalom-like path, and a GL2 verb referring to such straight aspects would thus not be able to select a unique referent or a set of referents).

To summarize: it is possible to describe English verbs referring to path curvature by using the three-grain-level hypothesis. In order to make sure that the three-grain-level hypothesis is more than an ad-hoc vehicle for describing curvature verbs, we will consider whether the three-grain-level hypothesis is able to help us to formulate constraints on English GL0, GL1, and GL2 verb combinations in Section 3 and is able to help us to define English constructions referring to path curvature in Section 4. Both sections will look at some examples, without pretending to give an exhaustive overview.

3 GL0, GL1, GL2 verb chains

It is possible to combine GL0, GL1, and GL2 verbs in order to express path curvature. Consider the following example from Finnish:

(16)	*Hän meni*	*kotiin*	*mutkitellen*
	S/he went	home+ILL	zigzag+INF2+INS
	|	|	|
	V	PP	INF2+INS
	|	|	|
	GL0 verb	goal of the Path	GL2 verb

"She went home zigzagging"

In the example above, ILL refers to "illative case," INF2 refers to "the infinitival verb in the second infinitive (marker—*Te*-) instructive case form" (this infinitival form is similar to the Germanic gerundive adjunct, which is marked in English with the suffix *-ing*), INS refers to "instructive," V refers to "verb," and PP refers to "prepositional phrase." We use these and ensuing abbreviations in agreement with conventions in linguistics.

However, not all GL0, GL1, and GL2 verb combinations are possible in a particular language. For example, Nikanne and Van der Zee [22] observe that the following constraint operates in Finnish:

Infinitival GL0verb - Adjunct Constraint
* V[motion] - V[motion GL0]+ INF2+INS

This constraint refers to the fact that a GL0-verb may not function as an INF2+INS-adjunct if the main verb in the sentence is a motion verb. For instance, the following sentences are ungrammatical:

* GL1verb - GL0 verb adjunct
(17) * *Kivi kaarsi mäkeä alas mennen/tullen.*
* stone rolled hill-PAR down go-/come+INF2+INS

where PAR refers to "partitive case."

* GL2 verb - GL0 verb adjunct
(18) * *Käärme mutkitteli kiven alle mennen.*
* snake zigzagged stone+GEN under+ALL go+INF2+INS

GEN refers to "genitive case" and ALL to "allative case."

* MoM verb - GL0 verb adjunct
(19) * *Käärme kiemurteli kiven alle mennen.*
* Snake wriggled stone-GEN under-ALL go+INF2-INS

In Dutch it is not possible to have the highly context sensitive GL1 verbs as a gerundive adjunct. This means that it is possible to formulate a constraint on the use of gerundive adjuncts in Dutch based on the three-grain-level hypothesis:

Gerundive GL1 - verb Adjunct Constraint:
* V[motion] - V-ing[motion GL1]

This constraint rules out, for example, the following sentences:

(20) * GL0 verb - GL1 verb
* *Hij ging indraaiend/afslaand/inbuigend de straat in.*
* He went turning in/turning of/bending into the street

(21) * GL2 verb - GL1 verb
* *Hij zigzagde indraaiend/aflsaand/inbuigend de straat in.*
* He zigzagged turning into the street.

(22) * MoM verb - GL1 verb
* *Hij danste indraaiend/afslaand/inbuigend de straat in.*
* He danced bending of into the street.

In both Finnish and Dutch verb chains with motion verbs that stem from the same grain level are ruled out:

Finnish:

* GL1 GL1 (Conflict: two different shapes)
(23) ** Mies kaartoi kotiin koukaten.*
* man curved home-ILL make.hook-shaped turn-INF2-INS
* The man curved home making a hook-shaped turn.

* GL2 GL2 (Conflict: two different shapes)
(24) ** Käärme mutkitteli kiven alle sahaten.*
* snake zigzagged stone-GEN under-ALL "saw"-INF2-INS
* The snake wound under the stone "zigzagging."

Dutch:

(25) * GL0 GL0 (tautological)
** Hij ging reizend de berg af.*
* He went travelling down the mountain.

(26) * GL1 GL1 (tautological)
** Hij draaide (in)slaand de straat in.*
* He turned hitting (in) into the street.

(27) * GL2 GL2 (tautological)
** De skier zigzagde slalommend de heuvel af.*
* The skier zigzagged slaloming down the hill.

(28) * GL2 GL2 (contradiction)
** Het blad cirkelde zigzaggend naar beneden.*
* The leaf circled zigzagging down.

There is interaction with syntax here (based on scope). For example, *slalomde zigzaggend* ("slalomed zigzagging") is acceptable, whereas *zigzagde slalommend* ("zigzagged slaloming") is not, in the same way that *spiraalde cirkelend* ("spiralled circling") is acceptable, but *cirkelde spiralend* ("circled spiralling") is not. The story is thus more complicated, and the constraint needs to be refined in reference to syntax. However, even such a refinement must be phrased in terms of GL2 - GL2 combinations.

Chaining two verbs at the same grain level thus either leads to a contradiction, or the result is tautological.

The Finnish and Dutch examples have shown that language specific constraints on verb chains can be formulated by using the three-grain-level distinction. Can similar constraints be formulated in relation to English? In order to find this out we used two different methods: we used Google to search for certain verb chains in order to determine whether these occurred in English at all; and we presented 17 native English speakers with several occurrences of every possible verb chain that is logically possible under the three-grain-level hypothesis (see the Appendix), and asked participants to rate the acceptability of these verb combinations on a Likert scale from 1 to 7 (where 1 was highly acceptable, 7 was not acceptable, and intermediate values represented intermediate levels of acceptability).

The following combinations did not occur in Google, and received very low acceptability ratings (see examples 21 and 23 in the Appendix):

* GL1 verb - GL2 gerundive adjunct
(29) ** X curved/curves/curving zigzagging/slaloming/spiraling/winding.*

* GL1 verb - GL2 gerundive adjunct
(30) ** X arced/arcs/arcing zigzagging/slaloming/spiraling/winding.*

Interestingly, these combinations are possible if one or both words in the above combinations are considered as describing object curvature. For example (underlined):

(31) *... all of the <u>curves</u> zigzagging irregularly ...*

(32) *... hairpin <u>curves zigzagging</u> up the mountain ...*

The constraint following from (29)–(32) can thus be formulated as follows:

GL1 - Gerundive GL2 Adjunct Constraint:
* V[motionGL1] - V-ing[motion GL2]

This constraint excludes gerundive GL2 verb adjuncts in English which follow a GL1 verb if both verbs refer to Figure motion.

English also rules out GL1 motion verb - GL1 motion verb combinations:

(33) ** She curved arcing into the street.*

Again, the combination *curved arcing* is possible if it refers to object curvature instead of path curvature:

(34) *. . . curved arcing blades . . .*

In addition, the word combination in its path sense is possible if it is used in an adjectival manner:

(35) *. . . a beautiful curved arcing kick . . .*

It is thus only the GL1 motion verb - GL1 motion verb combination which is unacceptable.

In relation to English it is thus possible to formulate constraints on verb chains in terms of the three-grain-level hypothesis. In addition, we have seen that if English verbs in a verb chain can be interpreted as referring to object curvature instead of path curvature that these combinations are possible. In this sense English distinguishes itself from Finnish. In Finnish object curvature and path curvature verbs are kept separate. For example, there is a tendency in Finnish to use causative verbs for expressing path curvature and to use inchoative (i.e., change of state) verbs for expressing object curvature:

Path curvature:

(36) *Auto kaartaa* [car curve-(CAUS)-3SG]
(37) *Auto kiertää* [car curl-(CAUS)-3SG]

where 3SG refers to "third person singular" (e.g., *he* or *she*).

Object curvature:

(38) *Tanko kaartuu* [bar curve-(INCH)-3SG]
(39) *Tanko kiertyy* [bar curl-(INCH)-3SG]

In the next section we consider English constructions that refer to path curvature.

4 Constructions and path curvature

4.1 The notion of construction

Since the 1980's the notion "construction" has become more and more central in linguistics [6–10, 21, 23]. Constructions are units that license exceptional linking between form and meaning. By form we mean fragments of syntactic structure, lexical information, morphology, and sometimes even phonetics. A typical construction in English is, for instance, the construction:

as far as NP V{*know*, *remember*, *can tell*. . . }, S

where NP refers to "noun phrase." For example:

(40) *As far as I can tell this computer is the most advanced you can buy.*

This construction has a fixed syntactic structure and the choice of lexical items is partly fixed (*as far as*), partly open (the NP is a variable), and partly there is a choice from a set of (semantically close) words (verbs which can be, e.g., *know*, *remember*, *can tell*, or other related verbs or verbal structures).

The above construction is not referring to "far distance" (its literal meaning); its meaning refers to the speaker not taking full responsibility for the content or the truthfulness of sentence S. Thus, there is an exceptional mapping between the lexico-syntactic form and the meaning of the sentence.

There are also other closely related constructions that contain the lexico-syntactic structure *as far as NP. . .* , for instance, *as far as X is concerned S* indicating that what is said about the referent of X in S is only meant to apply to X. Constructions can thus be related to other constructions.

If we want to obtain a full picture of how path curvature is used in communicative situations we have to address whether there are any constructions referring to path curvature. We do this in the next section.

4.2 Constructions that indicate path curvature

The data we use in this section is based on the free description experiment in Section 5 and on a search for certain word combinations using Google.

In English there is a common path curvature expression using the construction *Vcause{do, make} a NP/NP-PLURAL*. In this construction the NP refers to a particular kind of curvature that is caused by the (non-explicit) subject of the causative verb. Examples of this construction can be formed from:

do/make a zigzag/spiral/circle/turn ...
do/make zigzags/spirals/circles/turns ...

For example:

(41)	*He's doing*	*zigzags*	*down the path.*
	V	NP-PLURAL	(optional PP-adjunct)
	CAUSE	GL2	(GL0)

The syntactic form *do NP* is used in many constructions (see, e.g., [30] on *do a NP* in which the NP is a proper name, as in *do a Chomsky*).

Another and related path curvature construction is *Vmotion{going, walking} in a NP/in NP-PLURAL*. Also in this construction the NP refers to a particular kind of curvature. The motion verbs that can be part of this construction are GL0 or MoM verbs. If GL1 verbs are used (e.g., *curved in a spiral/spirals*) the phrase refers to object curvature. Examples of this construction are:

going/moving/walking/running in a zigzag/spiral/circle/ ...
going/moving/walking/running in zigzags/spirals/circles/ ...

For example:

(42)	*The rabbit*	*went/walked*	*in a zigzag*	*(down the path)*
		V	$[_{PP}$ *in* NP$]$	(optional PP-adjunct)
		GL0/MoM	GL2	(GL0)

There are also constructions in which only the GL0 verb *to go* takes a curvature noun:

go zigzag, go circle, go spiral

The curvature nouns in the *Vgo NP* construction do not have an article; in this construction the curvature nouns behave more like an adjective, cf. *go crazy/wild*.

In Sections 2–4 we have shown that English verbs referring path curvature can be described in terms of the three-way grain level distinction, that this distinction can be used to explain constraints that operate at the English sentence level, and that this distinction can be used to define constructions in English referring to path curvature. In the next section we show how the three-grain-level hypothesis can be used to predict iconic gesturing when verbally referring to path curvature distinctions.

5 Testing grain level representation in English path curvature descriptions and accompanying iconic gestures

Iconic gestures accompanying speech play a role in activating lexical and spatial representations during language production. These gestures are produced more when spatial information is the topic of communication, and listeners' speech comprehension is influenced by their perception of iconic gestures (e.g., [1,18]). Since in normal communication not only the language produced, but also non-verbal information as found in iconic gestures plays a potentially important role, we investigated grain level representation in both language and iconic gesturing.

In Section 5.2 we will present an experiment in which participants were asked to describe how a rabbit moved across a computer screen. Verbal output and iconic gestures (whenever present) were recorded. In Section 5.3 we consider the results of the experiment. In the next section we first look at the predictions in relation to both language and iconic gesturing.

5.1 Predictions

Kita and Özyürek [11] have shown that the production of iconic gestures is influenced both by the language spoken and the spatial distinctions described. They, for example, showed English, Turkish, and Japanese speakers a cartoon in which Sylvester the cat swings on a rope from a high-rise on the right to a high-rise across the street on the left to catch the bird Tweetie. When describing this swing event adult English speakers conflated local and global curvature more in their iconic gestures than Turkish and Japanese speakers did, whereas speakers of the latter two languages produced more iconic gestures in which local and global curvature were represented separately. These results could be explained partly by the way in which English, Turkish, and Japanese lexicalize the description of a swing event. Whereas English lexicalizes both local and global path curvature with the verb *to swing*, Turkish and Japanese speakers do not lexicalize this information in a single verb: they describe local and global curvature in separate terms. Kita and Özyürek [11] talk about manner of motion and motion where we talk about local and global path curvature. Although we have shown [22] that GL2 verbs behave differently from, and thus need to be distinguished from manner of motion verbs, these differences are not important for a discussion of the gesture data as used here, and we have therefore used the terms local and global path curvature where Kita and Özyürek have used manner of motion and motion.

According to Kita and Özyürek [11, 12] results like these show support for the interface hypothesis: the idea that gestures originate from an interface representation which is constructed both on the basis of the perceived spatial features the speaker wishes to communicate and on the basis of the lexicalization pattern of a language. If speakers would produce gestures solely on the basis of what they had perceived (the free imagery hypothesis; e.g., [13]), there would be no differences in the gestures of the English, Turkish, and Japanese speakers, since all of these speakers had seen the exact same stimulus. If speakers would produce gestures solely on the basis of the lexicalization patterns in their languages (the lexical semantics hypothesis; e.g., [4]), the iconic gestures of English speakers would always conflate local and global curvature, and the iconic gestures of Turkish and Japanese speakers would always separate out local and global curvature. Since English, Turkish, and Japanese speakers do not show only one type of iconic gesture, but a mix—

influenced by the lexicalization pattern in a language and the spatial configuration they want to describe—it is reasonable to conclude that iconic gestures are produced both on the basis of the spatial features involved in the scene and the lexicalization pattern of the language involved.

In the experiment below we investigated several predictions in relation to the representation of grain levels in English path curvature descriptions and the accompanying iconic gestures. Firstly, we predicted that for clips portraying locally curved paths but for which no local curvature verbs or constructions existed (as defined on the basis of the three-grain-level hypothesis), participants would produce more clauses compared to clips for which local curvature verbs or constructions do exist. If no verb or construction is able to capture local path curvature, extra-lexical means would be necessary to describe local path curvature, thus requiring the production of multiple clauses. Secondly, in line with the interface hypothesis we predicted that participants would produce more conflated gestures (i.e., gestures conflating local and global path curvature) when lexicalized expressions or constructions relating to local and global path curvature are available as opposed to situations when lexicalized expressions or constructions relating to local and global path curvature are not available.

5.2 The experiment

5.2.1 Participants

Eighteen psychology undergraduate students from the University of Lincoln participated in the experiment, some of whom were rewarded with credits as part of an experiment participation scheme. All participants were native English speakers.

5.2.2 Materials

Participants were presented with 18 movie clips on a computer screen. Each clip portrayed a rabbit walking along a path. The path curvatures in each clip were different, as defined by Van der Zee [29] (e.g., the clips portrayed global path curvature, local path curvature, or both; smooth or non-smooth path curvature; Figure rotation or the absence of it, etc.). All movie clips were presented in a semi-random order: the first clip for each of the 18 participants corresponded with their participant number (i.e., participant 1 received clip 1 as their first stimulus, participant 2 received clip 2 as their first stimulus, etc.), with all remaining clips being presented randomly. Participants were seated in a chair at a desk with the computer screen in front of them. The experimenter was seated in another chair to their right. A camera registered each participant's verbal and gestural output.

5.2.3 Procedure

Participants were asked to describe to the experimenter *how the rabbit moved across the computer screen*. They were not asked to make gestures. Participants could go from one clip to the next at their own pace by clicking a button on the screen with a computer mouse.

5.2.4 Data scoring

For present purposes the responses of all participants in relation to only four clips were analyzed: all these clips portrayed the rabbit going towards the viewer along a globally straight path (see Figure 2), with clip 1 containing multiple non-smooth curvatures (a zigzag-like path), clip 2 containing multiple smooth curvatures (a slalom-like path), clip 3 containing one loop, and clip 4 containing six loops.

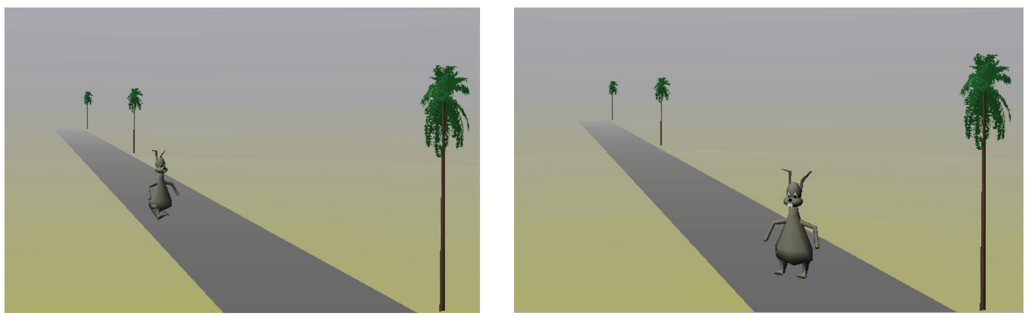

Figure 2: Example snapshots of the movie clips shown to the participants. In all clips the rabbit was portrayed as going towards the viewer along a globally straight path (the snapshot on the left). In clip 4 the rabbit made six loops while going down the path (the snapshot on the right shows the rabbit making its final loop). The background was slightly larger in the real clips.

The reason for selecting only these four clips was firstly that these clips are matched for global path curvature and perspective (global path curvature is straight in all clips, and the rabbit moves towards the perceiver in all clips). Secondly—by hypothesis—the first two clips allowed English speakers to use lexicalized items to describe local path curvature (i.e., a verb like *to zigzag*, as in *He's zigzagging across the path*, an example from participant 4), and constructions like *went/walked in a zigzag*, as in *It's walked in a zigzag down the path* (an example from participant 1). By contrast, the last two clips did not allow English speakers to use lexicalized items to describe local path curvature, since no verbs exist in English encoding "one loop" or "several loops" in a path. This ensured that English speakers could use free descriptions as in: *He's walking down a straight path and then about … a quarter of the way he does a full circle and then carries on walking towards me* (an example from participant 2).

The filmed responses by the participants were imported into Elan 3.2.0. The verbal output was converted into written text. In Elan this text was linked to the iconic gestures (whenever present) and the video images. For all verbal output two authors (Emile van der Zee and Urpo Nikanne) checked the produced clause structure per participant per clip on the basis of the written text, and for the gestures two authors (Uta Sassenberg and Emile van der Zee) determined (a) whether the produced gestures referred to path curvature, and if this was the case (b) whether the global and local curvature components were conflated or not. Conflicts in scoring were resolved by discussion, until a consensus was reached.

5.3 The results

A paired t-test revealed that the average number of clauses produced for the two clips for which lexicalized items existed to describe local path curvature was lower (mean = 2.64, standard error = 0.23) compared to the number of clauses produced for the two clips for which no lexicalized items existed (mean = 3.94, standard error = 0.27; paired t-test d.f. = 17, t = -4.861, $p < 0.001$). This confirmed our prediction in relation to clause structure.

In relation to the language produced it is furthermore interesting to observe that lexicalized or construction based local curvature descriptions that were used in correspondence with iconic gestures were mainly of the type *Vmotion{going, walking} in a NP/in NP-PLURAL*. In only one case the verb *to zigzag* was used in correspondence with a gesture. The construction *Vcause{do, make} a NP/NP-PLURAL* was never used in correspondence with any gestures. The following examples are illustrative of the language output of the participants:

(43) when the rabbit walked towards the participant while there were sharp angles in its path when moving from one side of the road to the other side of the road:
It's walking in a zigzag, [from the middle of the screen] to the end of the screen.

(44) when the rabbit walked towards the participant while there were smooth angles in its path when moving from one side of the road to the other side of the road:
It's walking down the road but [meandering from side to side but always in a forward direction].

(45) when the rabbit walked towards the participant with one loop in its path:
[He's walking down a straight path]$_1$ and then about ... a quarter of the way [he does a full circle and then]$_2$ [carries on walking towards me]$_3$.

(46) when the rabbit walked towards the participant with six loops in its path:
The rabbit was walking [along a road]$_1$, he ever so often [turned to his right]$_2$ [and turned around inside the road]$_3$ [and carried on walking again]$_4$.

Brackets above indicate the part of speech where a single gesture was made. Numbers refer to the number of gestures made.

Table 1 summarizes the correspondence between language and iconic gesture production. As expected, no constructions or local curvature verbs were used in relation to the clips containing one loop or six loops, since—by hypothesis—no such verbs or constructions exist in English for these types of path curvature. *Doing a circle* was excluded as a construction reliably describing a path with one loop or several loops, since this construction was never part of a larger construction describing the straight parts of the path at either end of the loop, even though free descriptions did take both straight parts into account.

In agreement with our second prediction more conflated iconic gestures were produced in relation to stimuli for which lexicalized items or constructions did exist (n = 12), as opposed to situations in which no lexicalized items or constructions existed (n = 1; chi-square test with d.f. = 1, $\chi^2 = 9.308$, $p < 0.0023$). Furthermore, in line with the three-grain level hypothesis and the interface hypothesis gesture conflation was absent (or curvature was encoded in separate local and global components) more for situations in which no lexicalized items or constructions existed (n = 28), compared to situations in which lexicalized items or constructions did exist (n = 11; chi-square test with d.f. = 1, $\chi^2 = 7.410$, $p < 0.0065$). In line with both hypotheses, the ratio of conflated gestures to non-conflated gestures was

	G 2 verb or construction was used; gesture conflation present	GL2 verb or construction was used; gesture conflation absent	No GL2 verb or construction was used; gesture conflation present	No GL2 verb or construction was used; gesture conflation absent
Two clips for which lexicalized items exist to describe local path curvature	4	6	8	3
Two clips for which no lexicalized items exist to describe local path curvature	0	0	1	28

Table 1: The correspondence between language and iconic gesture production. Numbers represent frequencies of occurrence.

larger when GL2 verbs or constructions were present (4:6, or in 40% of all cases), compared to when GL2 verbs or constructions were absent (9:31, or in 23% of all cases). Looking at the data from another angle, for stimuli for which GL2 verbs or constructions existed about as many participants produced conflated gestures compared to non-conflated gestures (10:11 ratio, or 48% of all cases), in contrast to stimuli for which no local curvature verbs or constructions existed (1:28 ratio, or 4% of all cases). Interestingly, even for stimuli for which local curvature verbs and constructions existed, but were not used, conflated gestures were used more (8:3 ratio, or in 73% of all cases), compared to stimuli for which no constructions or local curvature verbs existed (1:28 ratio, or 4% of all cases). In agreement with the interface hypothesis the use of conflated iconic gestures depended both on the stimuli used and on the English lexicalization pattern that was available—as defined by the three-grain-level hypothesis.

6 Conclusion

The main contribution of this paper is that we have demonstrated that a three-grain-level distinction [22] describes and explains path curvature distinctions in English language production and its accompanying gestures. More specifically, we have seen that our three-grain-level hypothesis is able to account for verb descriptions referring to path curvature in English (Section 2), that this hypothesis is able to explain constraints on sentence structure (Section 3), is able to explain the form in which constructions relating to path curvature can be defined (Section 4), and finally, that this hypothesis explains clause structure for English path curvature descriptions based on visual input, and in combination with the interface hypothesis [11] explains that native English speakers' gestures are influenced both by the language spoken and the local path curvature observed (Section 5).

The work in our paper has direct relevance for those working in spatial information science. Scale, spatial resolution, or grain has been observed to play a role in spatial information processing. Our paper shows that scale, spatial resolution, or grain also plays a role in natural language and its accompanying gestures. It remains an empirical issue whether the distinctions that play a role in spatial information processing can also be found in language, or whether a subset or different distinctions play a role in language as found in spatial information processing. These are interesting questions at the interface between spatial information science on one hand, and spatial language and gesture research on the other hand.

The work presented here also has its limitations: we have not undertaken a complete and exhaustive review of all verb chain combinations and constructions in English, nor have we studied all aspects relating to grain levels in the correspondence between language and gesture when speakers refer to path curvature (such as perspective, language-gesture mismatches, the relative importance of global and local curvature encoding in gesture, etcetera). Each of these issues deserves more comprehensive research in further studies.

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Appendix

Combinations of GL0, GL1, and GL2 verbs in sentences as presented to native English speakers.

1. The ball came curving into the net.
2. He went down the mountain zigzagging.
3. The cork spiralled arcing across the table.
4. The soft ball arced across the base moving.
5. He curved arching into the street.
6. The mini cooper wound zigzagging through the mountain pass
7. The granite stone curled across the ice moving.
8. The flea moved along the path crawling
9. He turned into the street zigzagging
10. The ship curved into the dock floating.

11. He turned into the street dancing
12. The tram arrived travelling at the station.
13. He danced down the mountain zigzagging
14. The mollusc crept through the water moving
15. The duck wandered through the water waddling.
16. He went traveling down the mountain
17. He zigzagged going down the mountain.
18. He danced curving into the street.
19. He went bending into the street.
20. The flies moved across the sky spiraling.
21. The bowling ball curved along the lane zigzagging
22. The fly curved onto the table travelling
23. The tennis ball arced across the net spiraling
24. The sugar cube arrived on his plate curling
25. The ball rolled curving through the field.
26. The raisin arced into the glass wobbling.
27. The hat floated through the air spiralling.
28. He zigzagged down the mountain dancing.
29. The snake slithered under the rock wriggling.
30. He went down the mountain trembling.
31. The hedgehog approached the tree staggering.
32. The F1 car spiralled zigzagging through the pit lane.
33. The rock came zigzagging down the slope.
34. The cone curved into the stream rolling.
35. The jet-ski slalomed curving across the water.
36. He danced going.
37. He zigzagged turning into the street.
38. He turned into the street going.
39. The turtle curved through the street travelling.
40. The car zigzagged down the street hurrying.
41. The beetle wandered around the table travelling.
42. The disc flew arcing through the air.
43. The bus ran down the hill winding.
44. He danced down the mountain trembling.
45. The train came moving down the tunnel.
46. The ship turned curving into the side-canal.
47. The puck curled curving into the goal.
48. He zigzagged slaloming down the mountain.