CHAPTER 7—COORDINATION PATTERNS

The discussion in this chapter illustrates one way that the coordination class construct can be used to make sense of the decision-making processes of different students--processes that are complex even for the relatively bounded tasks studied here. Students' judgments are compared and contrasted at a group level, in terms of the expectations and coordination processes discussed earlier. Causal net elements (expectations for realistic motion) and readout strategies that students brought to bear in the four tasks were discussed in chapter five. Coordination processes that led students to judgments of the computer animations were explored in chapter six. A quantitative visual description of some of the decisions reported by students in their interviews is presented in this chapter. It is suggested that the phenomenology of student decision-making presented here could provide a basis for understanding some of the response patterns presented in chapter four.

The decision path diagrams presented in this chapter display some of the decisions students reported in their interviews. Decisions are represented by nodes in the diagrams, and choices are represented by arrows. Arrows lead from a node to another node (another decision) or to a final identification of one animation as most realistic. The diagrams are based on the coordination pieces from chapters five and six, as well as on the numbers of interviewed students who reported making particular choices for particular decisions. The diagrams present some of the complexity of students' decisions in a way that allows for comparisons among students and among groups. Of course, much of the complexity inherent in student coordination is hidden; the decision path diagrams make some complexity digestible without hiding all of it. No claim is made that the diagrams directly represent students' coordination systems; however, they do represent the behavior of coordination systems for a pair of situations. This is useful in itself, and is useful as a step in exploring students' coordination systems.

Decision path diagrams will be presented for the one-ball and two-ball V-valley tasks. For each decision in the diagrams, the percentages of interviewed physics students and psychology students making each choice are presented. The diagrams highlight similarities in the coordination of physics students and psychology students for the one-ball V-valley task, and also with the coordination of psychology students for the two-ball V-valley task. In addition, the diagrams highlight the uniqueness of physics students' coordination in the two-ball V-valley task; their choices appear in a different part of the decision path diagram than do those of psychology students, a part of the diagram that was not accessible in the one-ball V-valley task. These similarities and differences in coordination echo similarities and differences in the response patterns presented in chapter four.

7.1 REVIEW: EXPECTATION / READOUT PAIRS

In chapter six, readouts were described as linking students' expectations about realistic motion to their judgments. The coordination process described most often by students was the observation of some feature of an animation (a readout) inconsistent with an expectation for realistic motion (a causal net element). This process allowed students to judge the animation as depicting unrealistic motion (judgments were sometimes overturned, or even forgotten, later). Several examples of this process, made with both accurate and inaccurate readouts, were described in chapter six. The description from chapter six is extended in this section with a list of the expectations most commonly expressed in the V-valley tasks and the readouts and judgments most commonly associated with each expectation for particular V-valley animations.

The following three tables consist of descriptions of how often each expectation was expressed by students in each group, the types of readouts associated with each expectation, and the negative judgments most commonly associated with each expectation. Table 7.1 includes expectations commonly expressed for both one-ball and two-ball V-valley tasks. Table 7.2 lists the three possible race outcome expectations. Table 7.3 includes two of the more common and easily interpreted subjective expectations for realistic motion. In section 7.2, many of these expectation / readout pairs will be implemented in decision path diagrams for the V-valley tasks.

Expectations commonly expressed for both V-valley tasks	
ACCELDOWN and DECELUP expectations for slopes	• Nearly universal for students with identifiable expectations. • Associated with fixed-referent and relative motion readouts. • Accurate readouts rule out [constvx] and [sl]; inaccurate DECELUP-related readouts rule out [real] animations.
NOGAIN	• Nearly universal in one-ball V-valley task; often not expressed by physics students in two-ball V-valley task. • Associated with fixed-referent readouts. • Accurate readouts rule out [fst] and [fsl] animations.
SAMESPEED expectation for initial and final shelves	• Common for physics students; rare for psychology students. • Associated with (sometimes imprecise) fixed-referent and (sometimes inappropriate) relative motion readouts. • Accurate readouts rule out [fsl] and [sl] animations. • Effect on two-ball judgments amplified by connection to TIE expectation and inappropriate relative motion readouts.

Table 7.1 Selected properties of expectations commonly expressed in one- and two-ball V-valley tasks, including potential effects of expectation / readout combinations on student judgments.

Students usually reported accurate ACCELDOWN-related observations. Readouts related to the DECELUP expectation were normally accurate for all animations except [real], which students often judged to violate the DECELUP expectation. Students'

NOGAIN-related judgments for the [fst] animations are described in chapter six; some students also reported NOGAIN-related readouts for the [fsl] animations. The SAMESPEED expectation was expressed by many more physics students than psychology students; SAMESPEED-related readouts were apparently imprecise for one-ball animations, so that even students expressing the SAMESPEED expectation were sometimes unable to rule out the one-ball V-valley [fsl] animation. Thus, the SAMESPEED expectation appeared to have a small effect on many students' judgments in the one-ball V-valley task. The SAMESPEED expectation apparently had a more robust effect on physics students' two-ball judgments, through its connection to the TIE expectation; several physics students spoke as if the two expectations were interchangeable.

Race outcome expectations	• Associated with robust relative motion readouts. • Rule out two-ball animations with other outcomes.
TIE	• Strongly expressed by most physics students. • Expressed weakly by some psychology students.
VALLEYLOSES, VALLEYWINS	• Rarely expressed during V-valley tasks.

Table 7.2 Selected properties of race outcome-related expectations.

Many students expressed expectations related to the race outcome for the two-ball tasks. Of the three possible outcomes, only the TIE expectation was commonly expressed for the two-ball V-valley task. As described in chapter six, the TIE expectation was more commonly and more confidently expressed by physics students than by psychology students. Many psychology students expressed no preference for the race outcome in the two-ball V-valley task.

Selected subjective expectations expressed during V-valley tasks	
PAUSETOP	• More common for psychology students than physics students. • Expressed when choosing [fsl] despite NOGAIN-related readouts.
MAKEITUP	• More common for psychology students than physics students. • Associated with readouts about several animations.

Table 7.3 Selected properties of subjective expectations sometimes expressed in one- and two-ball V-valley tasks, including potential effects on student judgments.

Several students, more commonly psychology students than physics students, expressed experiential or holistic expectations. Two of these expectations, in particular, were expressed in a relatively consistent manner by several students, and seemed to have an impact on their judgments about animations. The PAUSETOP expectation was most commonly expressed by students who noticed that ball B nearly stopped at the end of the final slope in the V-valley [fsl] animations, but still judged that motion to be realistic. The MAKEITUP expectation, that ball B should not be "too slow" to roll up the final slope as depicted, was expressed in relation to many different animations; its most important use from the perspective of this chapter was in finding V-valley [fsl] animations unrealistic on the grounds that ball B should roll back down the slope.

7.2 REPRESENTING STUDENT COORDINATION

In the course of choosing animations as "most realistic", interviewed students reported several judgments about individual animations. In this section, the judgments of students from the two groups of interviews (twenty six students from a psychology course and twenty four students from a physics course) are represented quantitatively as path diagrams. The decision path diagrams were built from the coordination processes reviewed in the previous section as well as the feedback process described in chapter six. Judgment patterns for the one-ball and two-ball V-valley tasks are presented here. Comparison of diagrams for the two tasks demonstrates how the addition of the second ball increased the complexity and variety of student judgments.

The set of connections implemented in each diagram was determined by analysis of the decisions reported by interviewed students, where such analysis was possible. (Some decisions were not reported explicitly enough to allow for confident analysis; in addition, the twelve interviews with physics students that were not tape-recorded were useful only for counting judgments about which the interviewer happened to write notes.) The diagrams take the form of nodes, which represent decisions, connected by arrows to other nodes and to boxes, which represent final animation choices. Each connecting arrow is annotated with an abbreviated description of the choice represented by the arrow and the percentages of students who apparently made that decision. The percentages reported for each connecting arrow represent the fractions of students reporting a particular decision for the judgment represented by a particular node, so that percentages sum to 100% for arrows pointing out from a node. The percentages reported in a box (final choice) are calculated as the product of percentages for all arrows in the path leading to that box. Percentages in each box represent the overall fractions of students reaching that box, so that the percentages in all of a diagram's boxes sum to 100%. Percentages for psychology students (physics students) are labeled LT (MT), consistent with the group labeling system from chapter four.

7.2.1 One-ball V-valley decision paths

Figure 7.1 summarizes the judgment patterns of students from each group in the one-ball V-valley task. Decision paths for all students begin at node A and end at a box, which represents a final animation choice. Paths are intended to indicate a series of decisions; a student following the path ABE[sl] will have reported different decisions than a student following the path ABCD[sl], even though the two students identified the same animation as depicting realistic motion. Paths are not intended to depict a time order for decisions; two students following the path ABCD[real], for example, will have reported similar decisions, but will not necessarily have made or reported them in the same order. Node D, however, which represents a decision that involves feedback, can only be reached after all five animations have been judged unrealistic. (To indicate that the decision at node D involves feedback, arrows leading from node D have dashed lines and are described with italicized text.)

As the description of the arrow from node A to node B indicates, all interviewed students who described observations about the [fst] animation expressed the NOGAIN expectation. Thus, the decision paths for all interviewed students follow the arrow from A to B, and no interviewed student identified the one-ball V-valley [fst] animation as realistic. The decision paths of students reporting accurate ACCELDOWN-related readouts about the [sl] and [constvx] animations follow the arrow from B to C. Some students did not object to the motion depicted on the slopes of the [sl] animation; their decision paths follow the arrow from B to E, and from E (with a DECELUP-related objection to the motion depicted on the final slope in [constvx]) to the box labeled [sl].

Students whose decision paths reached C fell into three categories. Some students did not object to the [real] animation and did object to [fsl] for one of several reasons (some students found [fsl] unrealistic due to NOGAIN-related readouts, some students found it unrealistic due to SAMESPEED-related readouts, and some student reports were coded as MAKEITUP-related judgments). Students in this first category identified the motion depicted in the [real] animation as realistic. Other students reported an inaccurate DECELUP-related readout for [real] and did not object to [fsl], leading them to identify [fsl] as depicting the most realistic motion. Still other students objected to motion depicted in both [real] and [fsl]. The decision paths of these students follows the arrow from C to D. A path through node D indicates that a student had objected to all five animations, so that choosing any animation as realistic required a process involving feedback. From node D, students revised either their readouts or their expectations of realistic motion to choose [sl], [fsl], or [real].

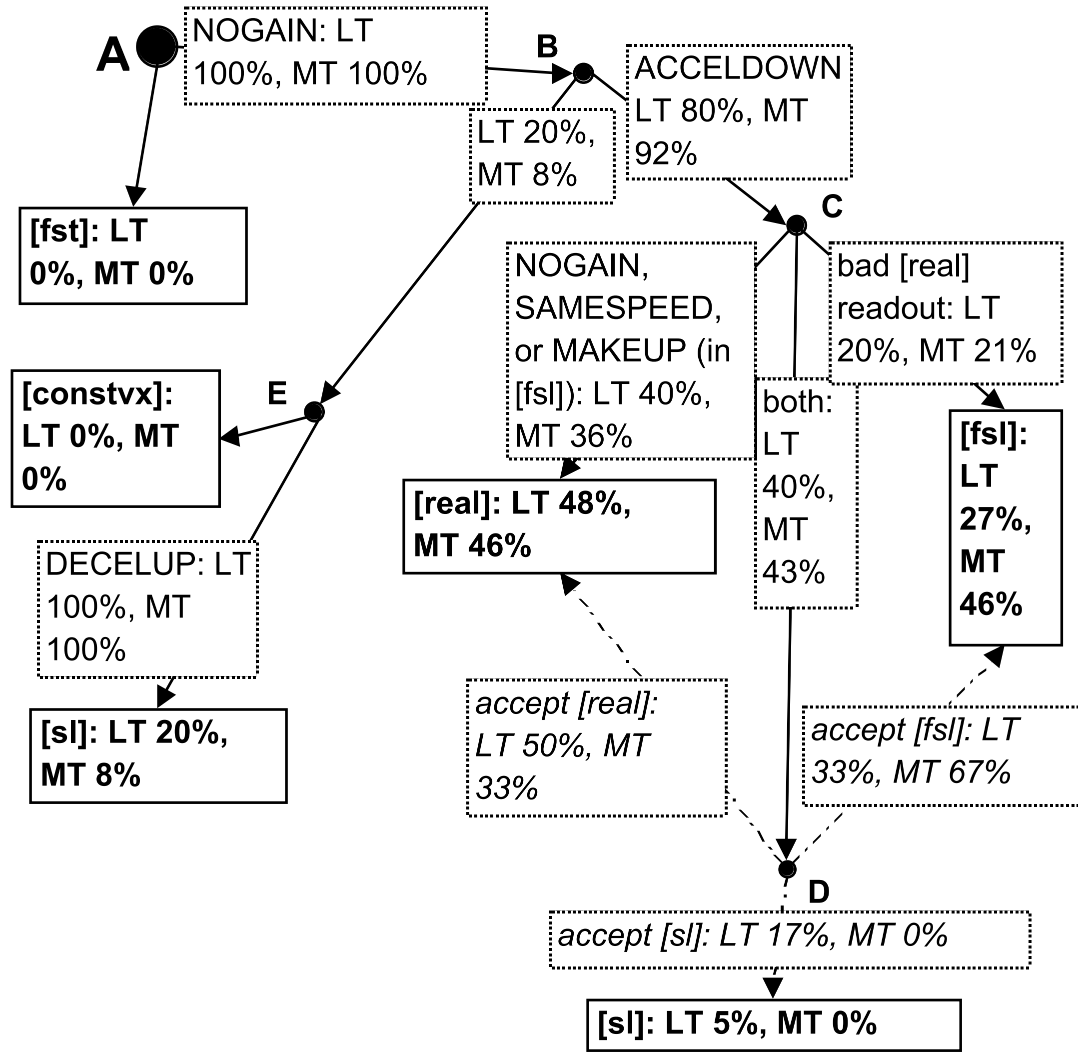

Figure 7.1 Decision paths for the one-ball V-valley task.

Illustrative quotations are provided in Table 7.4 below to demonstrate how the diagram in Figure 7.1 represents a particular student's decisions in the one-ball V-valley task.

Node progression	**Transcript excerpts from Felix, a physics student, in the one-ball V-valley task**
A → B (NOGAIN)	*Alright, that looks a little funny, because **it almost comes to a stop there and then picks up speed**.*
B → C for [sl] (ACCELDOWN)	*...seems like, oh, 3[sl]'s wrong.* <Interviewer: 3[sl]'s wrong?> *Well, **it looks like it doesn't pick up any speed on that slope**. It should...*
C → D → [fsl] (objects to [fsl] and presumably [real], but revises SAMESPEED expectation to choose [fsl])	*...Essentially number 4[fsl] again but still, I don't know, seems like it loses too much like **it almost comes to a stop, and <indecipherable> like perpetual motion once it comes to the top*** <Interviewer: So tell me what you like about 4[fsl]> *Um, the other ones it seem like, 'cause ideally when it comes to the top it should have the same velocity that it does right here...* <Interviewer: Why is that?> *Um, potential energy, gets transferred to kinetic energy, I mean the ball's rolling so you lose a little torque, but, um, it slows down considerably when it comes to the top of this, and that's ideally what it should do, so yeah, I guess let me say number 4[fsl] again.*

Table 7.4 Excerpts illustrating a physics student's progress through the one-ball V-valley decision path diagram.

The decision paths representing coordination by most psychology students (LT) and by most physics students (MT) are remarkably similar for the one-ball V-valley task. Except for a smaller percentage of LT than MT students reporting ACCELDOWN-related objections at node B, and somewhat different distributions of feedback-related judgments from node D, they are virtually identical when viewed at this level of detail. (Note, for example, that splitting the path from C to the [real] box into an arrow for each specific objection to [fsl] might reveal some finer-grained differences between path distributions for the two groups.) The coordination of the majority of students from each group led through node C (and for many students in each group, node D) to a final choice of [fsl] or [real].

7.2.2 Two-ball V-valley decision paths

Figure 7.2 summarizes the judgment patterns of students from each group in the two-ball V-valley task. Decision paths for all students begin at node A and end at a box, which represents a final animation choice. Node A represents the choice among race outcomes.

Two animations depict ball B losing the race, so that an expression of the VALLEYLOSES expectation did not narrow the field to one choice. Therefore, the "V-LOSE" arrow leads from A to B, where node B represents a choice between the [sl] and [fsl] animations. Students whose decision paths led to node B, and who made appropriate ACCELDOWN-related readouts and judgments, would follow the arrow labeled "slopes" to identify the [fsl] animation as depicting the most realistic motion; others might follow the arrow leading from B to the [sl] animation. Only one interviewed student for whom a decision path could be traced clearly expressed a belief that ball B should win the V-valley race. That student's decision path appeared to be AB[fsl].

Two interviewed students (one physics student and one psychology student) clearly expressed the VALLEYWINS expectation in the two-ball V-valley. Their decision paths appeared to follow the arrow labeled "V-WIN", and they identified the [real] animation as most realistic. Although these two students made specific motion-related objections to some animations, race outcome was apparently important to their decision, and they described ruling out some animations because of their race outcomes.

The majority of interviewed physics students (labeled MT in the diagram) and some psychology students (LT) clearly indicated their expectation that the two balls should tie in the V-valley race. Their decision paths led to node C. Three arrows lead from C, indicating the three choices observed among students who expressed the TIE expectation. Some students reported NOGAIN-related readouts for [fst] and no objections to [constvx]. The decision paths of these students followed the arrow labeled "NOGAIN" to the [constvx] box. Some physics students reported ACCELDOWN- or DECELUP-related objections to [constvx] but no objections to [fst]. Their decision paths followed the arrow labeled "slopes" to the [fst] box. Other students found the motions depicted in both [constvx] and [fst] to be unrealistic, so that their decision paths led to node D. Students reaching node D had ruled out each of the five animations as unrealistic, so that each arrow leading from node D represents a process involving feedback. To reach [constvx] from node D, a student had to align his or her expectations and readouts for [constvx] by revising expectations related to speed changes on the valley slopes or revising readouts related to speed changes in the [constvx] animation. Students who reached [fst] from D reported either distrusting their NOGAIN-related readouts or lowering their expectations about how realistic the motion depicted in even the "most realistic" animation should look. The third arrow, leading from D to G, indicates that some students lost confidence in the TIE expectation altogether, and re-considered the realism of non-tying animations.

The fourth arrow from A leads to E. This arrow indicates that some students (the majority of interviewed psychology students) expressed no clear preference for the race outcome. Nodes E through I in Figure 7.2 are very similar to nodes A through E in Figure 7.1. A slight deviation from a strict analogy is that students whose decision paths led from node G to the [real] box all reported NOGAIN-related objections to [fsl], rather than one or more of the objections encompassed by the arrow from C to D in Figure 7.1.

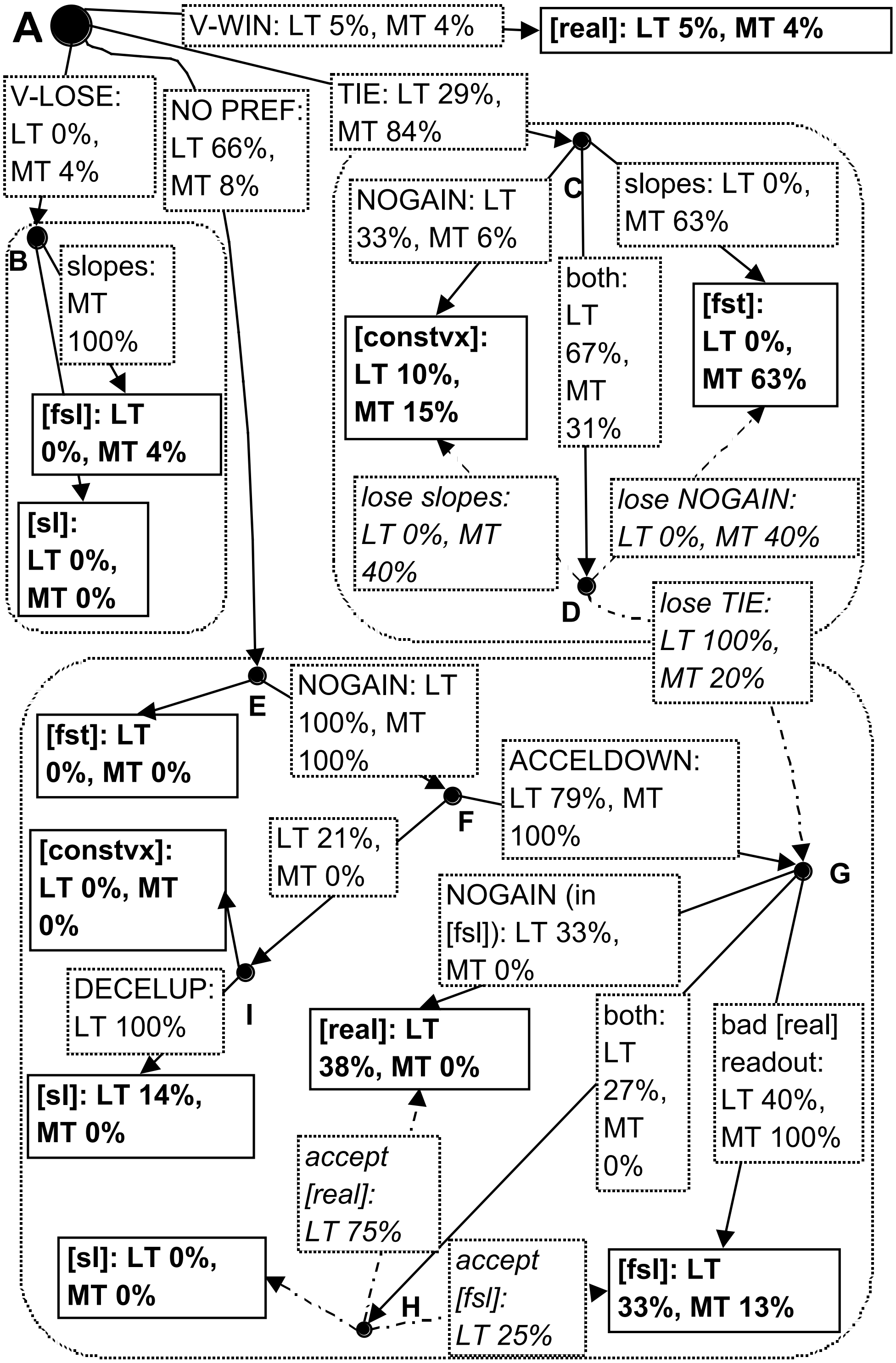

Figure 7.2 Decision paths for the two-ball V-valley task.

Illustrative quotations are provided in Table 7.5 below to demonstrate how the diagram in Figure 7.2 represents a particular student's decisions in the two-ball V-valley task.

Node progression	**Transcript excerpts from Stephen, a psychology student, in the two-ball V-valley task**
A → C and initially to [fst] (ACCELDOWN, DECELUP, TIE)	[in constvx]*...it doesn't seem that realistic to me that **they're at the same point all the way along**, I would imagine ... that it accelerates and decelerates* ... [in fst] ...***the top one seems to be going more at a steady speed while the bottom one goes faster and then slower and they end up pretty much at the same place that**, that seems realistic to me.*
DECELUP readout problem	[in real] *...that seems like the effect of **going up the hill doesn't really slow it down as much as I**...*
ACCELDOWN	[in sl]*...this one doesn't seem very realistic to me, number 4[sl],* ... ***going down that ramp it doesn't seem like that ball picks up really any speed**.*
TIE	[in fsl] ... *I still don't think that it would **slow down that much that it would, that the top one would pass it**, it doesn't seem as realistic to me.*
D → G NOGAIN causes feedback to lose TIE expectation	[fst again] *... I think I like ... 2[fst] ... hold on, hmm ... right **at the very end it seems to almost accelerate more than would be realistic** ... **it's really almost stopped there** and what makes it get that last little push to get over the top? So, now I'm not sure about 2[fst].*
G → [fsl] DECELUP readout problem	*I guess it's between 3[real] and 5[fsl] ... I guess I would go more with 5[fsl] because it does, **it doesn't seem like it slows down coming up the ramp as much on 3[real]**.*

Table 7.5 Excerpts illustrating a psychology student's progress through the two-ball V-valley decision path diagram.

The resemblance between the decision paths for the group of interviewed psychology (LT) students, for the two-ball V-valley task in Figure 7.2 and the one-ball V-valley task in Figure 7.1, is remarkable. The coordination of the majority of interviewed psychology students in the two-ball V-valley task led through node G (and for many students in each group, node H) to a final choice of [fsl] or [real], just as their coordination in the one-ball V-valley task led to the analogous section of the one-ball V-valley decision path diagram. Most of those students expressed no clear preference for the race outcome, so that their decision paths led from node A to node G through nodes E and F. Even among psychology students expressing the TIE expectation, however, most decision paths did not end in the TIE-related section of the decision path diagram, but instead passed through nodes C and D to node G. The group of interviewed psychology students appears to have made similar coordinations for the one-ball and two-ball V-valley tasks. Although individual psychology students may not have coordinated invariantly across the two tasks, the collection of decision paths taken by the group as a whole did appear to be consistent across the two tasks. As a group, the interviewed psychology students were not particularly sensitive to the shift in context from the one-ball to the two-ball task. (Note that relative motion readout strategies could be implemented in the two-ball task but not in the one-ball task, so there may have been coordination differences, even for students completely free of race outcome expectations, that would not be apparent from the diagrams as constructed here.)

In contrast, the collection of two-ball V-valley decision paths for interviewed physics students differs markedly decision paths for the same group of students in the one-ball V-valley task. Decision paths for the majority of physics students in the two-ball V-valley task ended in the TIE-related area of the decision path diagram, leading through node C (and for some students, node D) to a final choice of [fst] or [constvx]. In the one-ball V-valley decision path diagram, there is no analogous section. The collection of decisions made by the group of interviewed physics students appears, from this point of view, to be highly sensitive to the one-ball to two-ball context shift.

7.3 COMPARING WITH LARGE N PATTERNS

In chapter four, V-valley response distributions were presented for large groups of students. Among the patterns found were that:

- LT and MT students produced similar response distributions for the one-ball task;
- MT response distributions for the two-ball task were very different from those for the one-ball task; and
- LT response distributions for the two-ball task were more similar to one-ball response distributions than to two-ball MT response distributions.

How do these patterns relate to patterns of coordination? Similarities and differences in response distributions do not necessarily correspond to similarities and differences in underlying coordination processes; Figure 7.1 and Figure 7.2 show that the same response can be reached through different coordination paths, while similar coordination paths can lead to choices of animations with different features. For lecture presentations of the tasks, no information about students' coordination is available. However, coordination patterns for interviewed students, presented in the previous section, can be summarized as a virtual echo of the response patterns described above. Among the patterns found were that:

- the decisions of LT and MT students were distributed over similar paths for the one-ball task;
- the decisions of MT students for the two-ball task were distributed very differently from those for the one-ball task; and
- the decisions of LT students for the two-ball task were distributed over paths more similar to one-ball decision paths than to two-ball MT decision paths.

The similarity in patterns raises the possibility that LT and MT students in the large group presentations of the tasks may have used coordination processes similar to those used by the interviewed students. Figure 7.3 and Figure 7.4 suggest that this may be the case. Each figure presents the response patterns of a large group of students alongside the percentages reaching each response in the path diagrams. (Note that the "path diagram" percentages are not identical to the response patterns for the complete groups of interviewed students. They represent only the 15-20 interviewed students from each group for whom decision paths could reasonably be determined.) Error bars proportional to the square root of the number reaching each response are shown, using a nominal sample size of N=20 for the path diagrams.

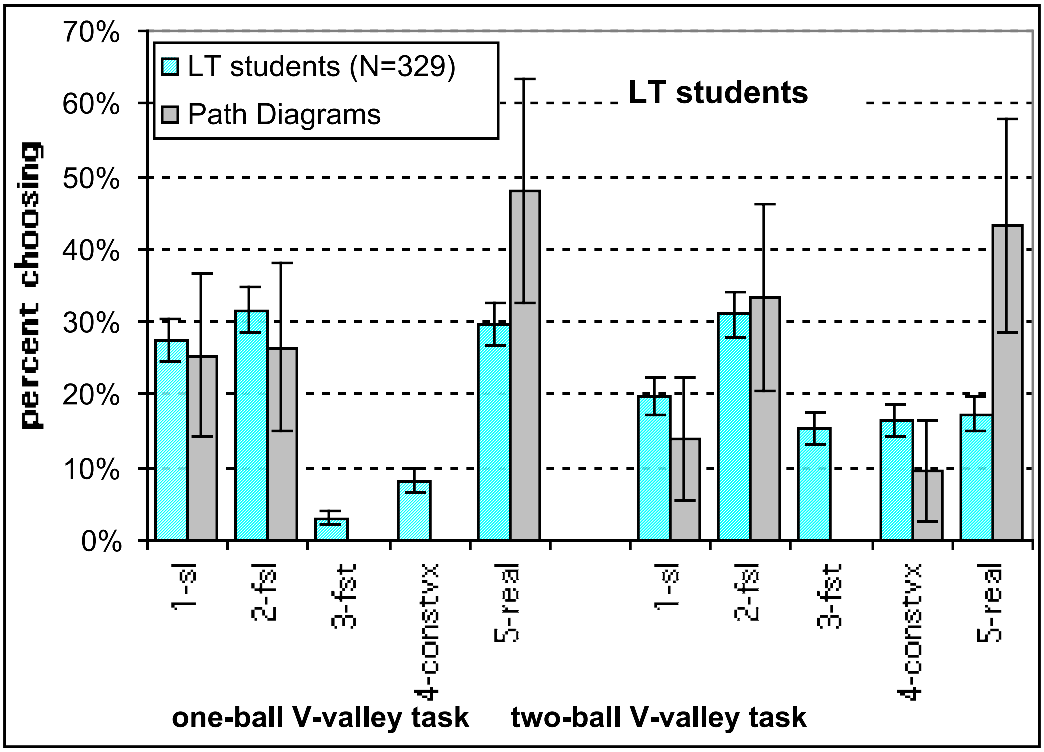

Figure 7.3 LT students: V-valley comparison charts for Path Diagrams vs. Large N data.

For LT students, the pattern of responses is similar for the large groups of students and for the path diagrams, although the path diagrams lead to the [real] animations with a higher frequency than did students in large groups.

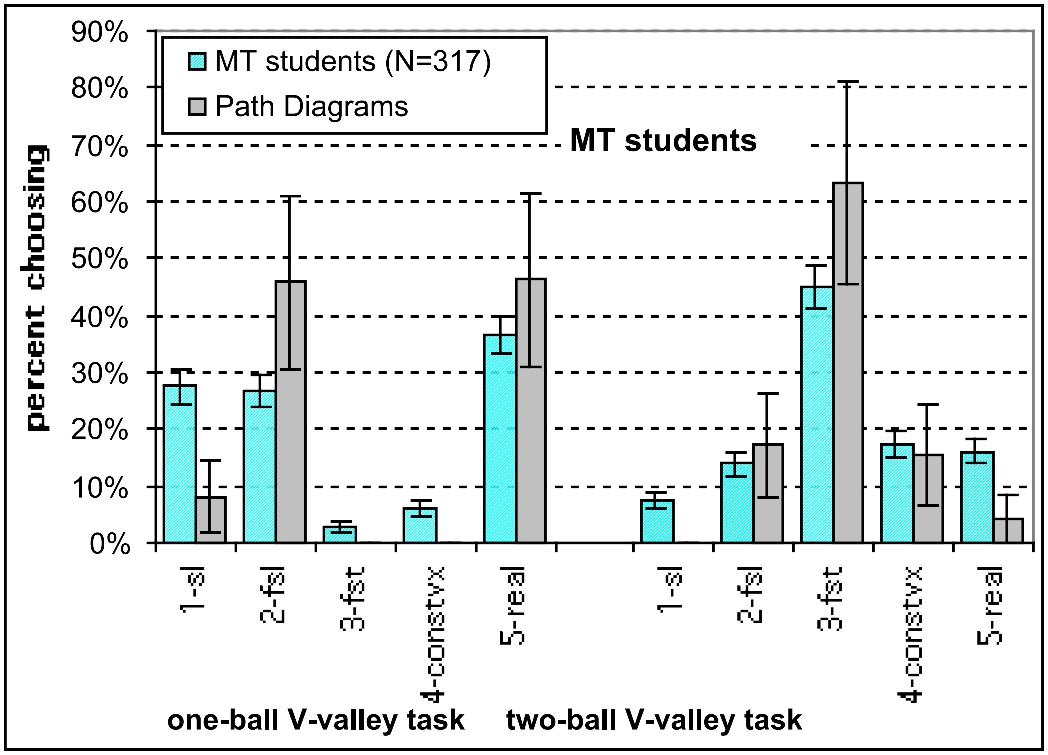

Figure 7.4 MT students: V-valley comparison charts for Path Diagrams vs. Large N data.

For MT students, response patterns are also similar for the large groups of students and the path diagrams, although the path diagrams lead to the one-ball [sl] animation with a lower frequency than did students in large groups.