On describing what is perceived: Seeing 'velocity' vs 'push' in moving objects

Geoffrey P. Bingham

University of Connecticut

and

Sverker Runeson

University of Uppsala, Sweden

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It took centuries in the history of science to develop the notions found in Newtonian mechanics such as force, mass, momentum, acceleration, and velocity. The Aristotelians instead referred to pushes and pulls, and what they called 'natural motion', fire naturally moves up, water down, etc. The scholastics attributed a special power of movement called impetus to moving objects not in contact with a mover. It seems to me that this history is ignored when the human perception of the Newtonian *velocity* of motion is assumed to be veridical in the perception of motion. So it was assumed for the first century or so of perceptual psychology during which Brown (1931), Wallach (1939), and others attempted to measure thresholds and difference limens for velocity perception. They assumed implicitly that velocity is perceived as such. This assumption went unchallenged dispite anomilies such as the so called 'appearance effect' found by Piaget et al.(1958) and also by Cohen (1964). An object moving at a constant velocity and appearing from behind a visual barrier seems to move at a very high velocity initially and then to drop to a slower constant velocity. In addition, Johansson discovered that simple harmonic motion appears constant during the majority of the motion, slowing down somewhat only at the ends despite the fact that the oscillating bright spot is continually either accelerating or decelerating. Finally, Johansson and Jansson in 1967 performed studies on the perception of free fall. They found that these motions were seen as constant velocity motions despite their near constant acceleration.

In a decade of research performed from 1967 to 1977, Sverker Runeson sought to challenge the assumption that Newtonian kinematics is seen as such. In '67 and '68, he ran pilot studies on the perception of various types of vertical motion. He had observers describe the motion aloud while he took notes. The motions used were constant acceleration, constant velocity, constant acceleration with slight deceleration at the very end, and constant acceleration which stopped for an instant at the halfway point and then continued again at constant acceleration. Observers tended to describe constant acceleration as constant velocity motion with some acceleration towards the end. The constant velocity motion was often described as jerking at the beginning followed by constant velocity, or initially fast and then slower constant velocity. The constant acceleration with decelerating end was described as constant velocity motion with some braking at the end. The constant acceleration, stop, constant acceleration movement was described as falling, bounce, falling, or constant velocity, bounce or stop, then constant velocity.

Initially, Runeson asked observers how much the various motions resembled free fall. Observers described the constant acceleration motion as most like natural free fall. But Runeson discovered a problem with this judgment. The problem was with observer knowledge. All of Runeson's observers knew that free fall is accelerated motion. They would use 'free fall like' and 'accelerated' as synonyms interchangeably. However, when Runeson did not ask explicitly for free fall judgments, or when this part of the task was forgotten in describing the motions, observers judged constant acceleration motion as constant velocity motion, sometimes getting confused or changing their minds when they realized the contradiction. This sort of problem occurred throughout these studies. Descriptive vocabulary derived from courses in physics interfered with descriptions of perceptual phenomenal experience. Observers were often afraid of being tricked. Runeson was forced to assure them that he was not interested in testing their conceptual knowledge, but rather in accessing their raw, uninterpreted phenomenal experience. Still observers were often suspicious and confused. They seemed to lack confidence when attempting to report their phenomenal experience, often avoiding reports that didn't look sensible according to their preconceptions. In addition, they were also often confused about the Newtonian notions of velocity and acceleration. Such confusion has been noted by other researchers in the field, for instance, by Gottsdanker (1962). This conceptual confusion added to the difficulty of separating conception from perception in these experimental tasks. The results reflect this to some degree as you will see.

Runeson (1974) performed studies involving motions in a forced choice task, in which observers were to choose the motion which appeared more constant. The motions used included constant acceleration, constant velocity, deceleration, and various decreasing accelerations. Both vertical and horizontal motion tracks were used. The result was that the decreasing accelerations were most often picked as looking constant. Runeson reported that his observers were distressed by the task of having to combine many different _types_ of seen velocity changes into a single comparison. He next used a method which would reveal the nature of those types of seen motion. He asked observers to draw graphs of the seen velocity of motion over the course of the motion, graphs, therefore, of velocity versus position. He used the same motions as previously used. _Motion functions_ define relative changes of velocity during a motion. Different motion functions used can have the same average velocity to control for overall duration of the motion event. Use of motion functions allows scaling of average velocity values without loss of identity. In his first graphing study, Runeson used three different average velocities, 10, 20, and 40 degrees of visual angle per second. The track was 35 degrees long so motion durations ranged from 3 seconds to close to 1 second accordingly. Runeson categorized the resulting graphs as Decelerating Stepwise, Decelerating Gradually, Constant, Accelerating from an Initial Velocity, and Accelerating from Zero. (Use overhead. Show main results.) The main results were a predominance of constant graphs for decreasing acceleration motions and a large number of decelerated stepwise and gradually decelerated graphs for constant velocity motions. These results were invariant over changes in the average velocity.

In subsequent studies, Runeson replicated these results. He also showed that a partially occluding random texture hedge had no effect on the results, that observer triggering of the motions to prevent surprise had no effect, that shortening the length of the track by a third also had no effect. He used an 'electronic occluding edge' to test an entry version of the motion functions where the moving spot started just behind a visual barrier. The effects were the same. Finally, he occluded the middle third of the track to test a re-appearance condition. Piaget and others had called the jerk at the beginning of the constant velocity motion an 'appearance effect'. No such results obtained in the re-appearance condition demonstrating that this was not strictly an appearance effect.

But what was it, then? Runeson suggested that his results constituted evidence for a special Perceptual Concept of Velocity or what he called the PCV. "The perceptual concept of velocity is most probably 'defined'", he suggested, "in such a way as to make natural movements easy to describe... (it) includes or presupposes the normal ways of starting and stopping." Runeson referred to the motion usually seen as constant, a motion with an initial acceleration to a constant velocity as a 'natural start' motion. In his displays, this was generated with an equation used to describe constant force motion with resistance proportional to the velocity squared. (Illustrate with overhead.) Runeson suggested that this type of motion is typical owing to factors in the terrestrial environment such as friction, inertia, and rate limitations such as those found in muscular contraction. Such 'natural motion' would have a simple look, he surmised, whereas 'un-natural motion' would look more complex. The sudden start of the instantaneously attained constant velocity motion is un-natural since no object with inertial mass can start to move without a continuous accretion of velocity. Thus, description of this motion would be more complex according to the PCV.

Subsequent to performing this research, Runeson went on in his 1977 dissertation to initiate the study of the perception of 'dynamic events'. Most recently, he has formulated a perceptual principle called KSD or Kinematic Specification of Dynamics which states that it is not the kinematic properties of events that are seen (or need to be seen) as much as the dynamic properties. Velocity and acceleration are not seen so much, he suggests, as mass, force, momentum, elasticity, etc. These dynamic properties act as constraints on events. They constrain the kinematic form of an event and as such are revealed to the perceiver through that kinematic form. Hence, Runeson claims, kinematics specifies dynamics. He has shown that lifted weight can be judged accurately in video displays of people lifting weight were only moving patches of light attached to the lifter's joints can be seen. Weight, a dynamic constraint on the activity, can be seen in the kinematics of the event.

Last year, I went to Sweden to work with Sverker on research related to the KSD principle. Sometime during last fall, I happened to mention while in Sverker's company his having demonstrated that we can't see the initial acceleration in falling objects. Sverker went bug-eyed and exclaimed that that is not at all what he meant to show! I'm a Gibsonian, he said, I'm not trying to demonstrate things that people can not see! But, said I, what about the title of your paper? 'Velocity _not perceived_ as such'? Yes, responded Sverker, _'as such'_, that is, as Newtonian velocity. Initial acceleration is not perceived _as such_, that is, as Newtonian acceleration. After all, I showed that we notice when the initial acceleration is missing, so we must apprehend it in some sense. We do so in terms of a specifically perceptual concept of velocity. Hmmm, said I and off I went to re-examine Sverker's basic results. Three things bothered me. The first two derived from his idea of natural motions. First, 'natural motions' implies that there should be 'un-natural motions'. I wasn't convinced that the 'jerk effect' in the constant velocity motions was a product of 'un-natural motion'. What is 'un-natural' is the discontinuity, the specifically instantaneous attainment of moderate velocity. But with steep continuity, sudden but continuous increase of velocity the 'jerk effect' prevails. So called 'natural starts' that are too abrupt give the jerk impression. Second, I was suspicious of Sverker's use of a simplicity metric. Simplicity or complexity are relative. Sverker's use was relative to description. However,I prefer not to think of the job of perception as providing descriptions. Rather, following Gibson I prefer to think of the task of perception as guiding activity. It's not obvious how these ways of perceiving start events are more parsimonious relative to tasks of guiding action. Third, Sverker's more recent claim that we are more attuned to the dynamic constraints on events than to its kinematics _as_ such seemed to me to conflict with the idea of a perceptual concept of velocity. Velocity afterall is a kinematic notion.

Then it hit me. The observers were not describing the kinematics of the motions despite instructions to graph velocity. They were describing the dynamics in a way. This is what I thought. They are describing the constant force of the constant force motion with friction implicitly assumed. After all, the Aristotelians did not conceive of friction as a force. Their version of force was the more anthropomorphic 'push'. Perhaps the observers were graphing 'push'. In the constant velocity case, what observers might be describing is an impact or more specifically, what Michotte called 'launching'. Observers were most hesitant in drawing the beginning 'jerk' of this motion. No wonder, if its launching that's to be described, since the launching object is invisible. Further confusion might be added by using a kinematic notion to describe dynamic properties.

Johansson reported his results on the perception of sinusoidal motions in a 1950 paper entitled "Configurations in the perception of velocity'. In a footnote in that paper, as I discovered a week ago, he reports the following. (Use overhead to describe 'recoil effect'.) When two spots move sinusoidally 180 degrees out of phase so that they overlap at the turn around point in the center of the display, the event can be seen as either a passing of the spots or as a recoil. Johansson found he could guarantee the recoil impression by raising one of the motion tracks just slightly relative to the other so that the spots do not quite overlap. The result in judgments of velocity is that velocity does not seem to decrease at the recoil, as it normally would in the sinusoidal motions. Rather, velocity seems to increase sharply just around the recoil. Michotte (1963) likewise reports that in the perception of collisions, in launching where one object is standing still initially, there is the impression of increased velocity around the point of contact, inside what he called the 'radius of action'. I spoke with Sverker on the phone the other day. He said that he had examined this effect with more natural looking collisions that include compression of the objects. The effect was reduced in these displays though still present. It was increased a great deal by inserting a very brief pause into the event at the point of collision.

Sverker and I decided to attempt to replicate Sverker's earier results by asking observers to graph 'push' in the same displays. (Use overheads to describe displays.) The moving ring was produced on an oscilloscope screen and projected on a ground glass screen. The observer viewed the display from the opposite side through a large plexiglas collimator lens system, allowing normal head movements without change of the angular properties of the display. The projection screen was dimly backlit and irregular pieces of masking tape were stuck to it except for a horizontal clearance in which the motion occurred from left to right. The motion track length was 30 degrees. The track was crossed by a dotted line at one third of the distance from the left edge of the screen. The moving ring entered from the left edge of the screen for the constant velocity motion and the constant deceleration motion. The ring appeared at standstill just to the left of the dotted line and then started moving for the natural start motion, the constant acceleration motion, and for another constant velocity motion.

In an initial condition, the area to the left of the dotted line was occluded by an 'electric occluding edge'. Hence, the ring could not be seen until it emerged at the dotted line. Observers judged each motion function twice in a random order. In the next condition, the visual barrier was removed. However, observers were instructed to begin judging the motions only when the ring had passed the dotted line. Again, the motion functions were judged twice in a random order. Finally, the occluded condition was run again for a single judgment of each motion function. The average velocity of the motions after the ring crossed the dotted line was 20 degrees per second. The motion functions were generated and administered by means of a large and continually expanding special analog hybrid computer that Dr. Runeson built and continues to build in his spare time.

Two groups of subjects were run. One group was asked to judge velocity as before. The other group was asked to judge 'push'. Due to the problem of interference of knowledge of Newtonian physics, it was necessary to describe the ring to observers in the 'push' condition as a hockey puck that was being pushed across a table top by someone with his/her hand. Observers were asked to judge how hard that person was pushing at each point in the movement.

Results in the two conditions are the same and both replicate previous results. The only difference of note in the 'push' condition was the occurrence with one observer of consistently inverted graphs.

Now, what do we conclude? Results are identical for velocity and for push. Do we say velocity is really perceived or push or both...? I think the up-shot is that we can reject the idea of a restricted Perceptual Concept as such. Rather, the results seem to indicate that motion functions constitute information about what is happening in the events. In one case, sudden, close to instantaneous acceleration to a constant velocity specifies a launching, an object being suddenly propelled by something, whereas more gradual acceleration to a constant velocity specifies constant force motion similar to free fall or rolling down inclined planes. It is not the absolute values of the velocities or average velocities that is so important as shown by Runeson's first graphing experiment, rather, it is the motion function that is intrinsically meaningful for perceivers. But this result is not altogether new or recent. Folks at Uppsala have been studying motion functions for some time now. Recall that velocity includes a speed component and a direction component. Sverker and I varied motions with respect to speed without paying much attention to variations with respect to direction. However, Johansson and others have been working for years with motion functions where variations in direction were studied without much attention payed to variations in speed. The cycloid is a good example. There Johansson showed that the spatial configuration of movements of points relative to one another can specify a moving object, in the case of the cycloid, a rolling disc. von Hofsten et al. have shown that variations in speed can specify movement of a point in depth. Research has also been done with more complex motion functions or kinematic forms which vary significantly in both speed and direction of as many as forty eight points. Johansson (1973) introduced investigation into what he called biological motion with a description of his point light technique. It has been demonstrated that kinematic displays of moving point light people can contain information specifying moving people and what they are doing, information for properties of performers such as gender, identity, effort, or fatigue, and for length of throw of an invisible thrown object as well as weight lifted.

In the studies performed by Runeson and myself, we established that motion functions constitute information for the perception of events. However, it is difficult, nay impossible really, to further evaluate the exact nature and use of what observers see in our motion displays. The problem is that in the selection of our motion functions in the construction of our displays, that selection was not well grounded in a good, common, everyday event that we could turn to for intuitions and further insight. We did not employ good Brunswikian representational design. What is required for a thoroughgoing understanding of the origins of various motion functions and their significance for the perceiver is that the natural constraints (dynamic, energetic, etc.) on the perceived event be described and understood.

In our experiments, we are left to speculate as to the nature of relevant constraints and this has greatly hampered our immediate progress and understanding. For instance, concerning the sinusoidal or simple harmonic motion used by Johansson and largely seen as constant motion by observers, Runeson speculated that such motion is natural since it is exhibited by swaying tree branches. However, it is also interesting to note that human reaching motions often exhibit the same kinematic form, that is, the hand moves in a straight line with symmetric acceleration and deceleration. In fact, such movements have been modelled as products of critically damped mass-spring systems.

There are reasons to believe that human motion is a particularly good, or appropriate example of motion to study in human motion perception. Homo Sapiens are a social species. They perform tasks cooperatively. In so doing, it is important for them to be able to see properties of co-workers in activity such as whether they are too weak or fatigued, in order to see whether they need help and if so what sort of help. So, it would not be surprising if human perceptual systems were particularly well tuned to the perception of characteristics of human motion.

It is useful to consider a crude taxonomy of the types of motions typically encountered in the pre-industrial environment of perceivers. The Aristotelian categories it seems to me are a fair and convenient guide. Following this guide, we find that there is motion induced by air motion, the pressure of wind blowing leaves, trees, and clouds. There is the motion of flowing water; the upward flickering of fire. Occasionally, pieces of earth move, rocks fall and fruit drops from trees. However, I wonder how important these kinds of motion were in the evolutionary development of perceptual systems. I suspect that none of these cases of motion was as prevalent nor as important as the remaining case, animate motion and animate induced motion as seen in a spinning-wheel or in a thrown object. As examples of animate motion, there is the seen motion of the self, the motion of predators, the particularly interesting in the light of the above considerations. Johansson and Jansson asked observers to adjust the speed of a film projector running a film loop of various free fall events. The idea was to adjust the speed for the most natural appearing free fall. The experimenters were interested in the accuracy of adjustments. You may imagine my surprise when I discovered that Johansson and Jansson used films of Olympic divers, high-jumpers, and pole-vaulters for the study. They found that observers could adjust these films fairly accurately. They compared adjustment accuracy of films depicting run-jump-fall-and landing with those only depicting the fall and found them to be the same although observers complained that the fall only films were more difficult, requiring greater concentration.

Now comes the kicker. Johansson and Jansson made and selected over their own films of jumpers so that they could control the effect on accuracy of adjust of the amount of arm and leg motion during the falls. They compared a minimum movement with a maximum movement condition. The result was that observers were much more inaccurate when limb motion was held to a minimum, hence forcing observers to judge only on the basis of free falling objects without the benefit of the accompanying animate motion. The result seen to indicate that human perceivers are better attuned to the specifically animate motion. An interesting result indeed.

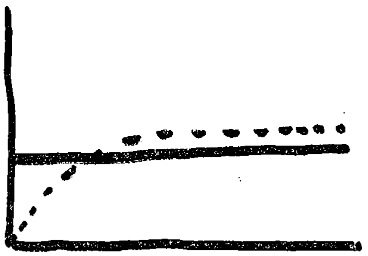
motion of prey, and the motion of those around one with whom one has social relations, other people and friends and co-workers of other species such as dogs, cats, and hunting birds. Indeed, if there were selection pressures in the evolutionary attunement of our perceptual systems in motion perception, there were most certainly strong selection pressures to being well attuned to the characteristics of animate motion. It is interesting that primitive and early civilized man tended to antropomorphize inanimate forms of motion in describing them.

More to the point, the perception of animate motion recommends itself as a good case to study since the constraints on it are the same as those on many of the other types of motion named above. The dynamic constraints such as gravity, inertia, friction, elasticity all apply. In addition, however, animate motion requires consideration of the use of stored energy in the development of the power for motion. How this energy is stored, used, and replenished is an additional constraint on the resulting kinematic forms of animate motion.

In having my observers judge Aristotelian 'push', I was supposing that perceivers, in any case, human perceivers are particularly sensitive to the conditions of animate initiated motion, that is, to the constraints placed on animate induced motions by the energy using processes in human movement. Whether or not this is in fact the case remains to be revealed in ongoing research on the perception of human motion.

I would like to close by relating to you the results of Johansson and Jansson's 1967 study on the perception of free fall which are

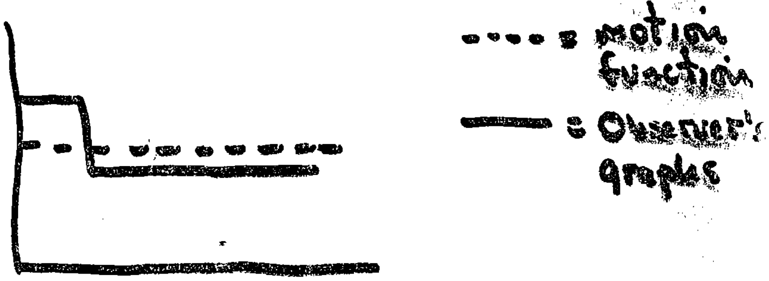
Basic Result



"Natural Start"

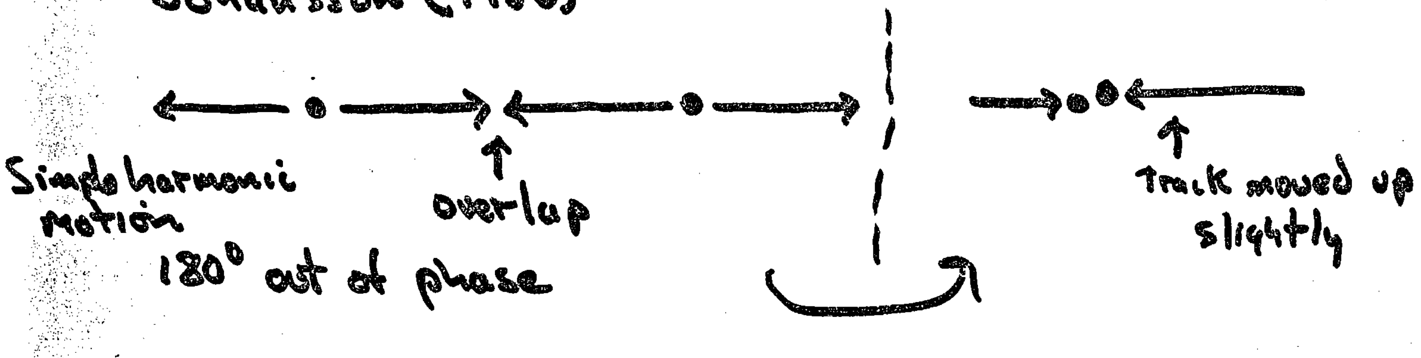
$$\frac{dv}{dt} = F - \alpha v^2$$

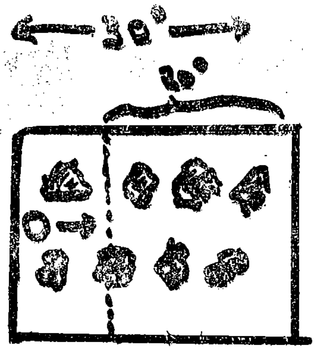
Acceleration to Constant Velocity described as Constant Throughout



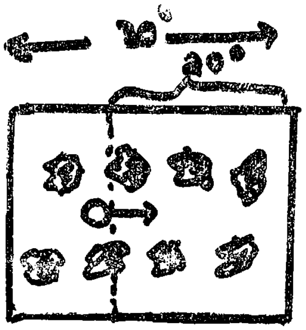
Constant Velocity described as initially quite high then dropping to a moderate constant velocity.

Johansson (1950)





Constant Deceleration
Constant Velocity at Edge



Constant Acceleration
Constant Velocity at Line
Natural Start

average vel. = 20°
past line.

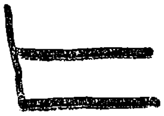
Categories

D_s = Decelerated Stepwise :

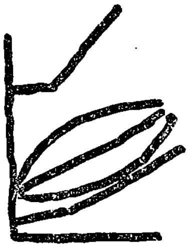
D_g = Decelerated Gradually :

or

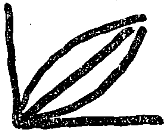
Const. = Constant :



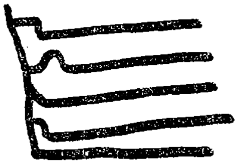
A_i = Accelerated from an Initial Velocity :



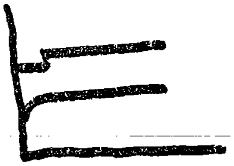
A_z = Accelerated from Zero :



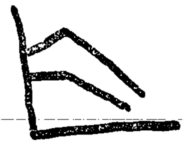
X = Decelerated irregularity at beginning :



✓ = Other irregularity at beginning :



or



or

( ) = Reversal

%'s Runeson (1974) 10 O's

40°/s

	Const. Decel.	Const. Vel.	Nat. (FA 35)	Const. Accel.
Ds	70	70		
Dg	30			
Const.		20	30	
Ai		10	50	30
A2			20	20

20°/s

	Const. Decel.	Const. Vel.	Nat. (FA 35)	Const. Accel.
Ds	70	60	10	
Dg	30	30	10	
Const.		10	40	
Ai			20	70
A2			20	30

10°/s

	Const. Decel.	Const. Vel.	Nat. (FA 35)	Const. Accel.
Ds	90	90	10	
Dg	10	10	10	
Const.			40	
Ai			20	30
A2			20	70

%'s Runeson (1975)

Norm 120's

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds	58	50		
Dg	25	25	8	
Const.			42	
Ai		16	16	33
A2			33	67
∩	16	8		

Norm 90's

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds	22	56		
Dg	67	22		
Const.		11	33	
Ai			44	56
A2			11	44
∩	11	11	11	

MIDI 90's

	~~Const. Decel.~~	Const. Vel.	Nat.	Const. Accel.
Ds		44		11
Dg		33		
Const.		11	44	
Ai			44	56
A2			11	33
∩		11		

Entry 90's

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds	44	44		
Dg	44	56	22	11
Const.			56	
Ai			22	89
A2				
∩	11			

5

%'s

Velocity (30's) (2/0)

Occluded Entry

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds		33		
Dg	100	17	17	
Const.		50	83	
Ai				83
Az				17
∩				

Visible Entry

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds			33	
Dg	100			
Const.		100	67	
Ai				67
Az				33
∩				

Push (60's) (2/0)

Occluded Entry

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds				
Dg	100	67		(8)
Const.		33	92	
Ai	(17)	(17)	8	92
Az				8
∩				

Visible Entry

	Const. Decel.	Const. Vel.	Nat.	Const. Accel.
Ds			17	
Dg	100	25	8	(17)
Const.		67	33	
Ai	(17)	8	25 (8)	67
Az			17	33
^				

Push (70's)

Velocity (70's)

Occluded Entry (a/o)

Push (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
21				(14)		100		Const. Decel.
	14			14	43	36	7	Const. Vel. at Line
14	14			7 (7)	36	57		Const. Vel. at Edge
	21				64	7	29	Nat.
7			7	93		(14)		Const. Accel.

Velocity (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
50		14				79	7	Coast. Decl.
14	14	7		36	36	7	14	Const. Vel. at Line
7					60	50		Const. Vel. at Edge
29				29	71			Nat.
			21	71	7			Coast. Accel.

Visible Entry (a/o)

Push (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
				(7)		100		Const Decel.
	43			(14)	21	43	36	Const. Vel. at Line
	14				64	29	7	Const Vel. at Edge
7	7			(7)	71	21	7	Nat.
14			7	93		(14)		Const. Accel.

Velocity (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
43						79	21	Coast. Decel.
14	36			21	21	29	29	Const. Vel. at Line
7	7			7	64	21	7	Const. Vel at Edge
	21				64	29	7	Nat.
21			7	93				Const. Accel.

Occluded Entry (1/0)

Push (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
14				(14)		100		Const. Decel.
14	43				57	29	14	Const. Vel. at Line
	29			14 (14)	43	43		Const. Vel at Edge
	14				86	14		Nat.
			14	86				Const. Accel.

Velocity (70's)

✓	X	∩	Az	Ai	Const.	Dg	Ds	
67		17				33	50	Const. Decel.
29	29			14	43	14	29	Const. Vel. at Line
	57				29	43	29	Const. Vel. at Edge
				14	86			Nat.
29				100				Const. Accel.