SUPERPOSITIONS

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SUPERPOSITIONS

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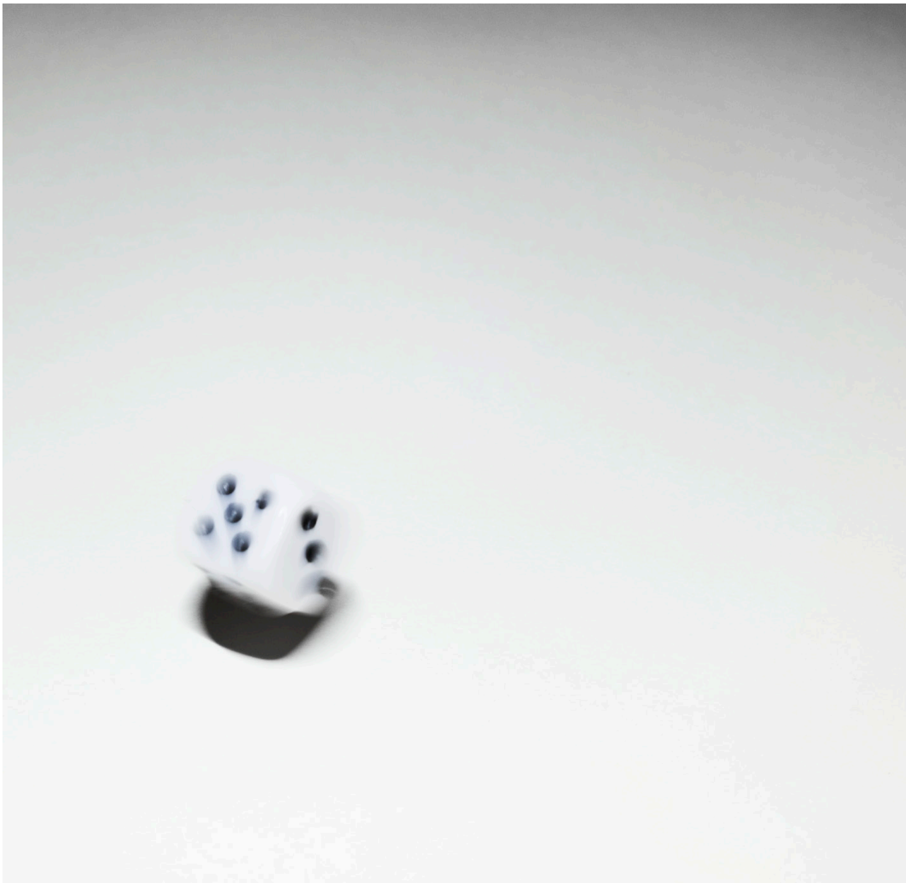

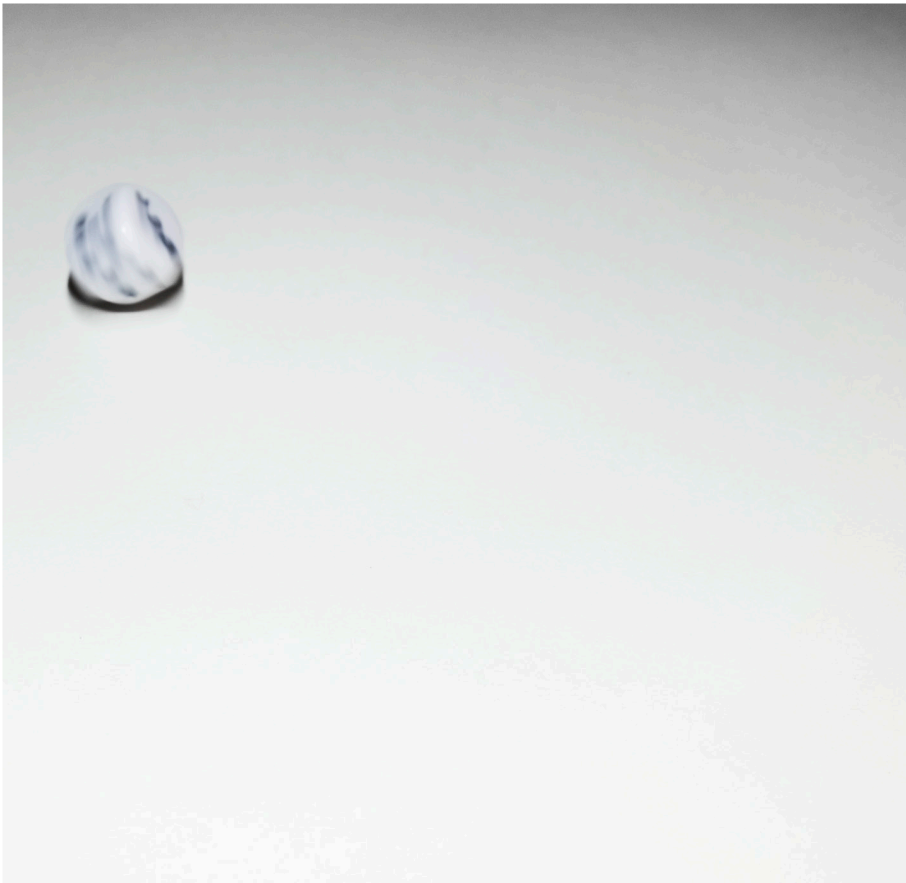

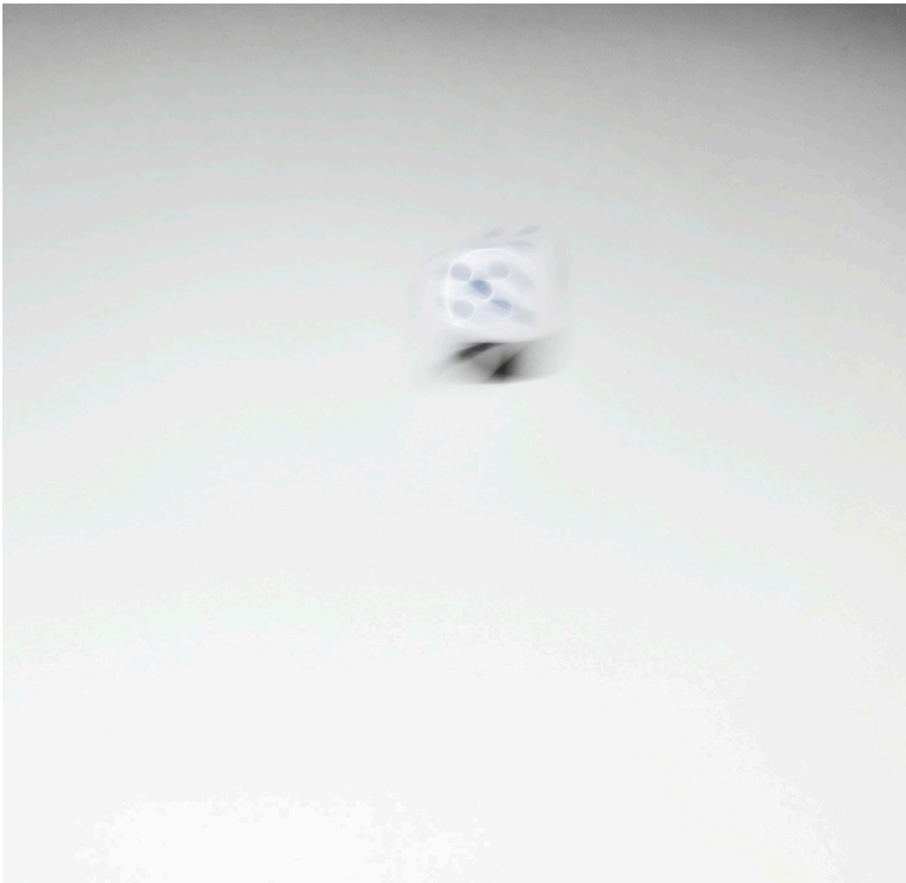

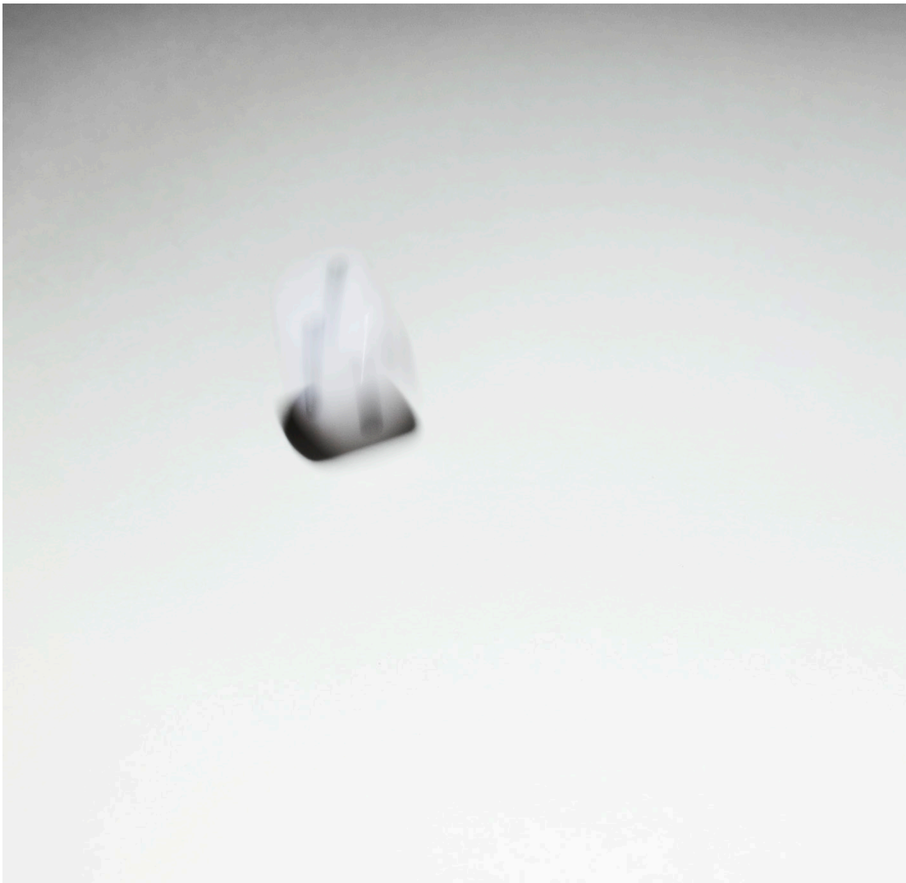

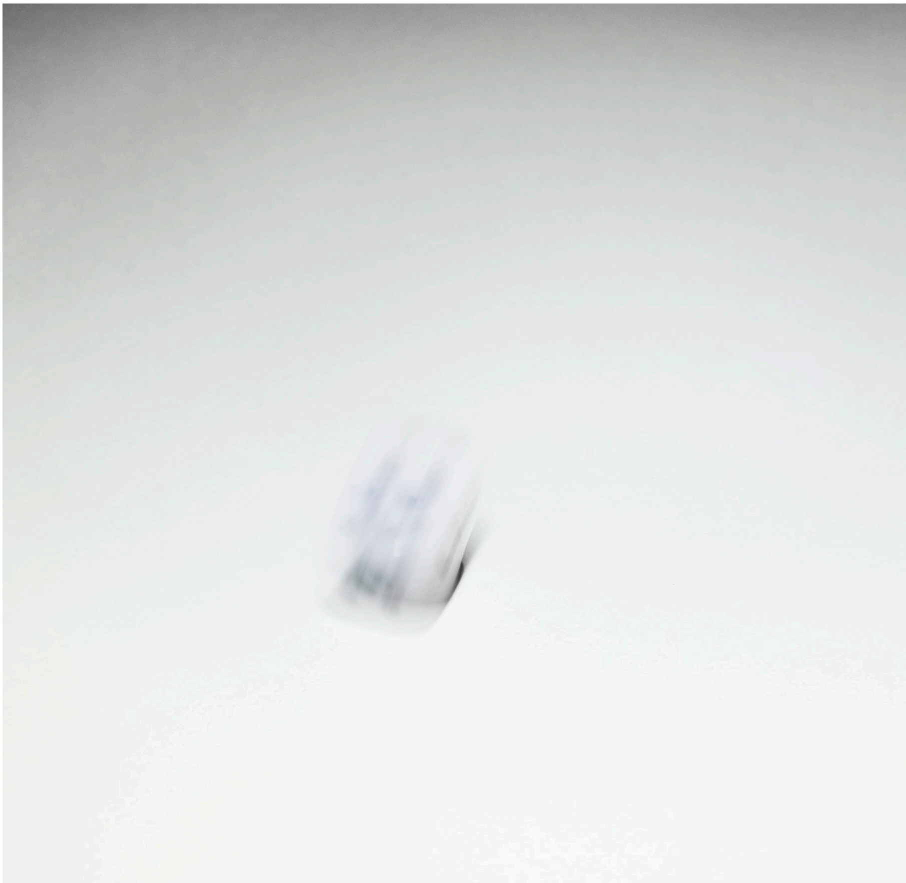

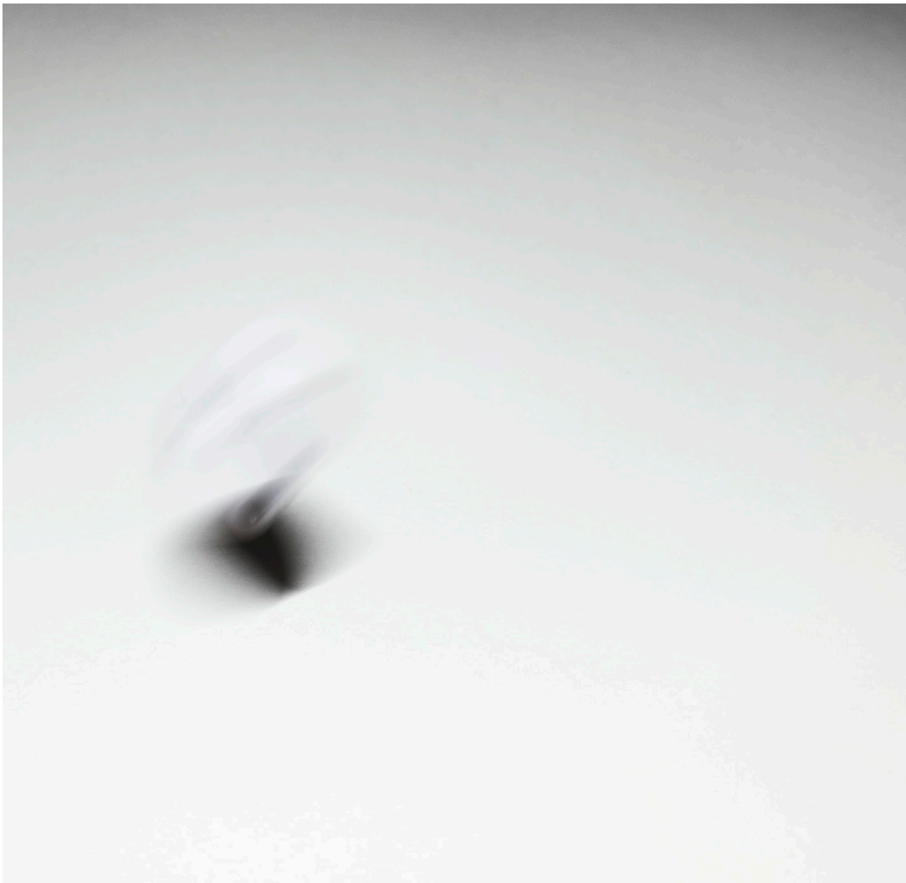

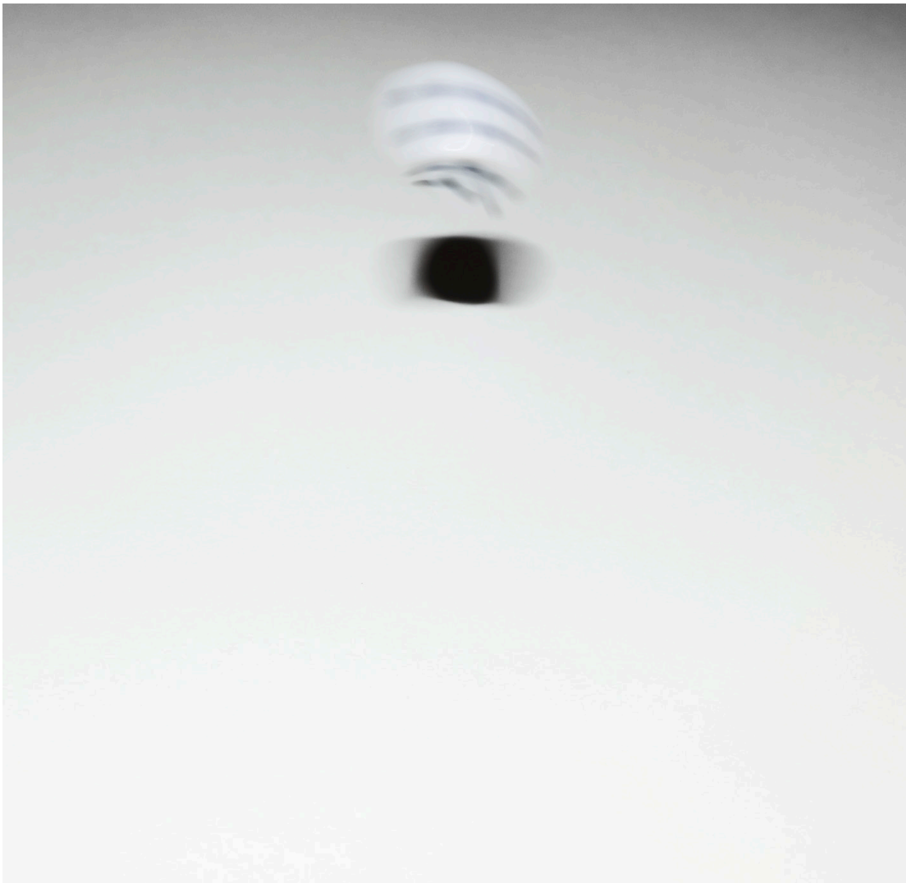

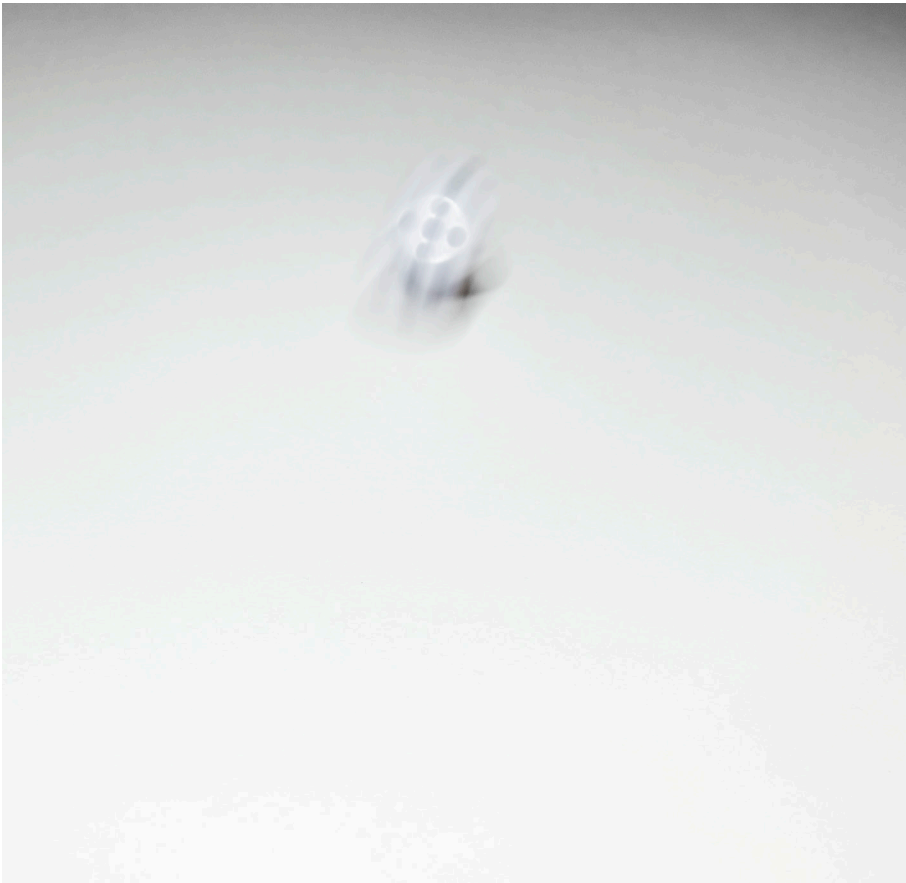

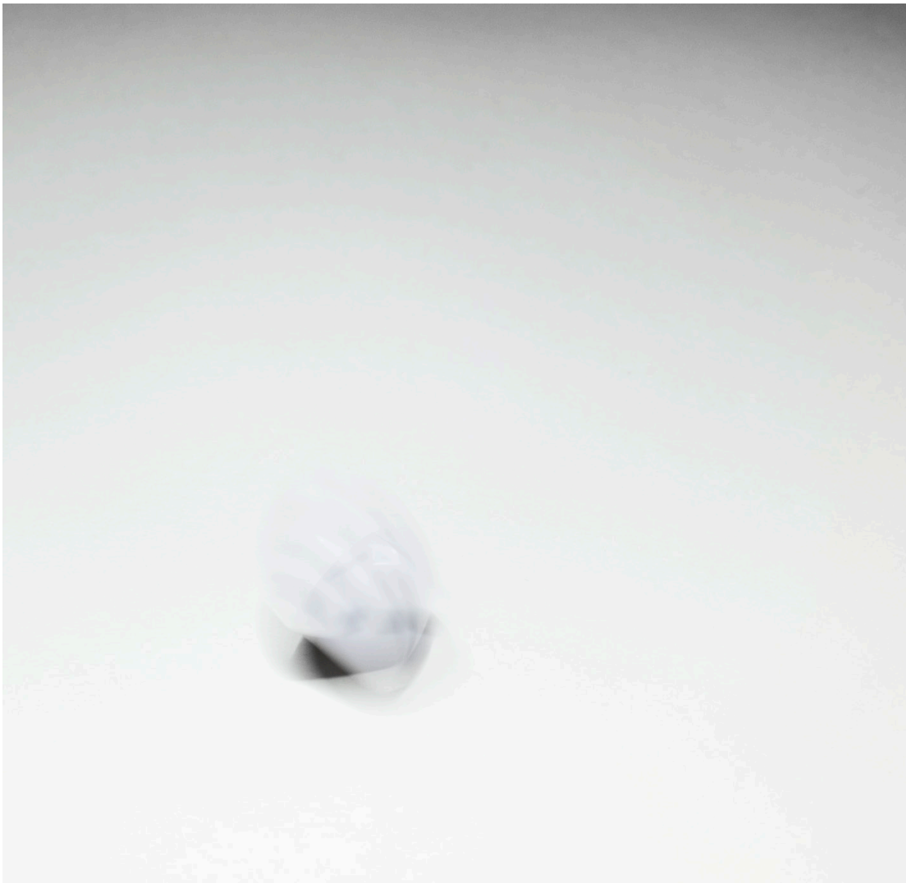

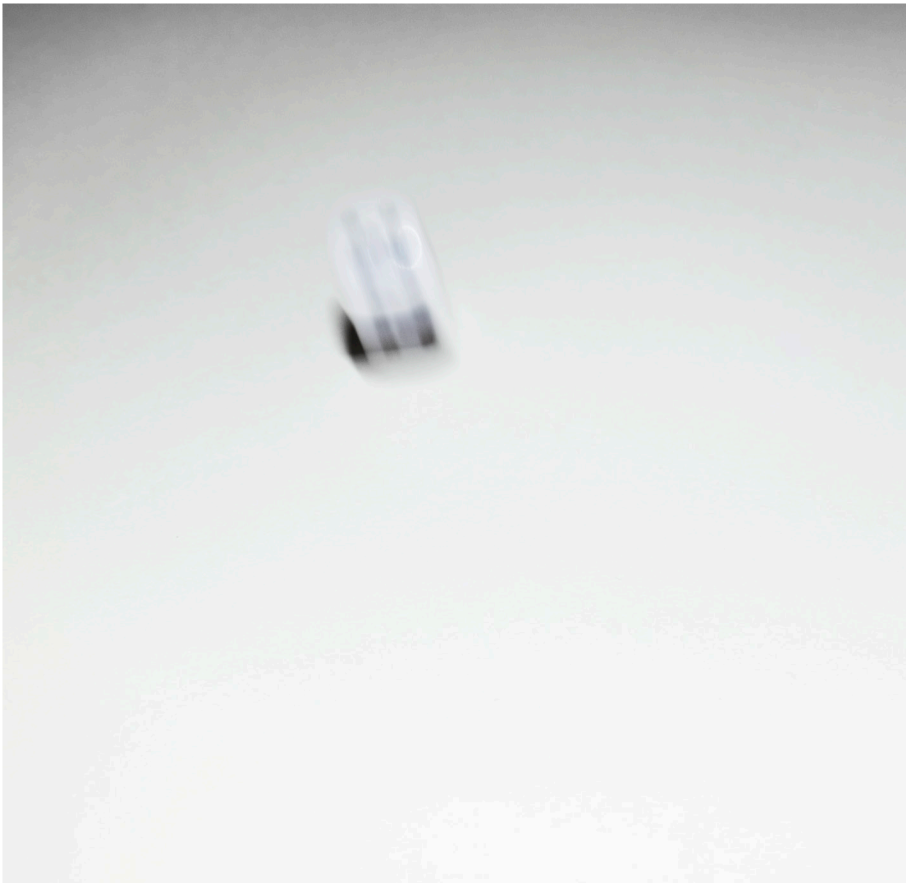

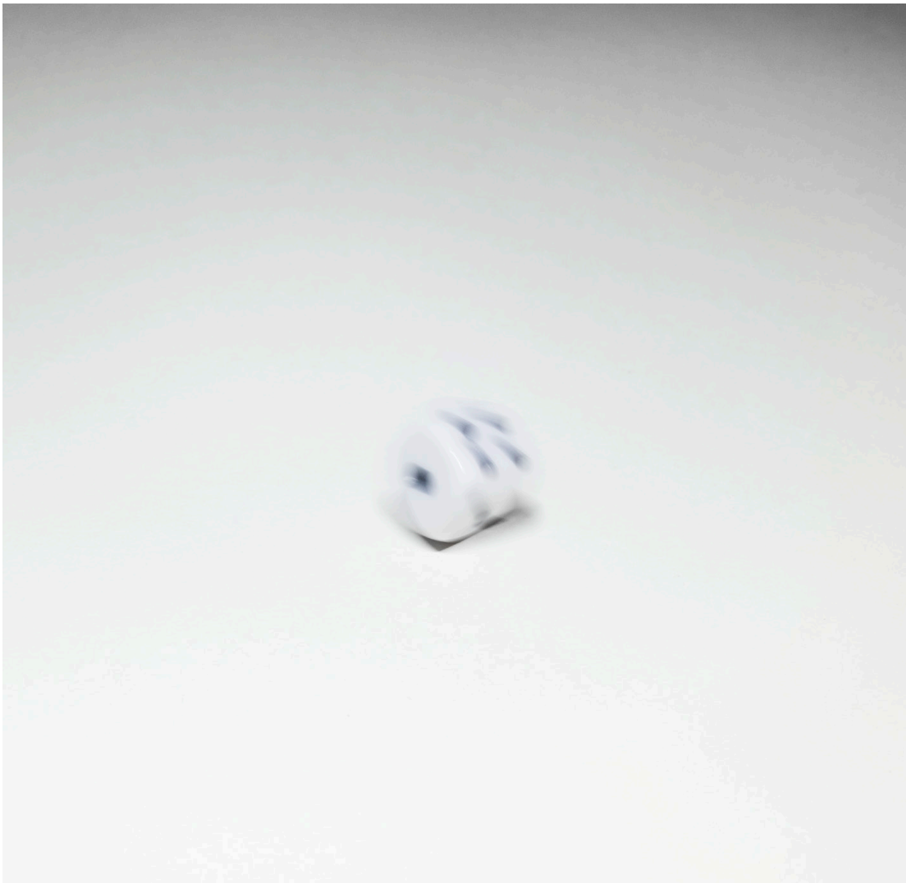

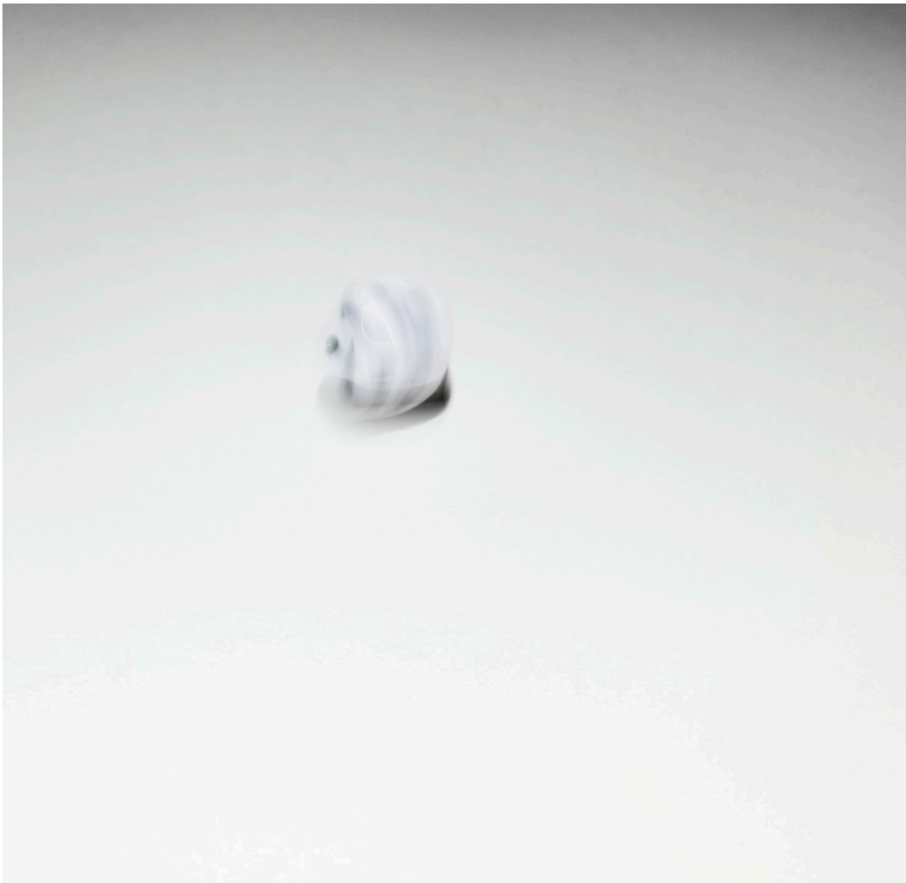

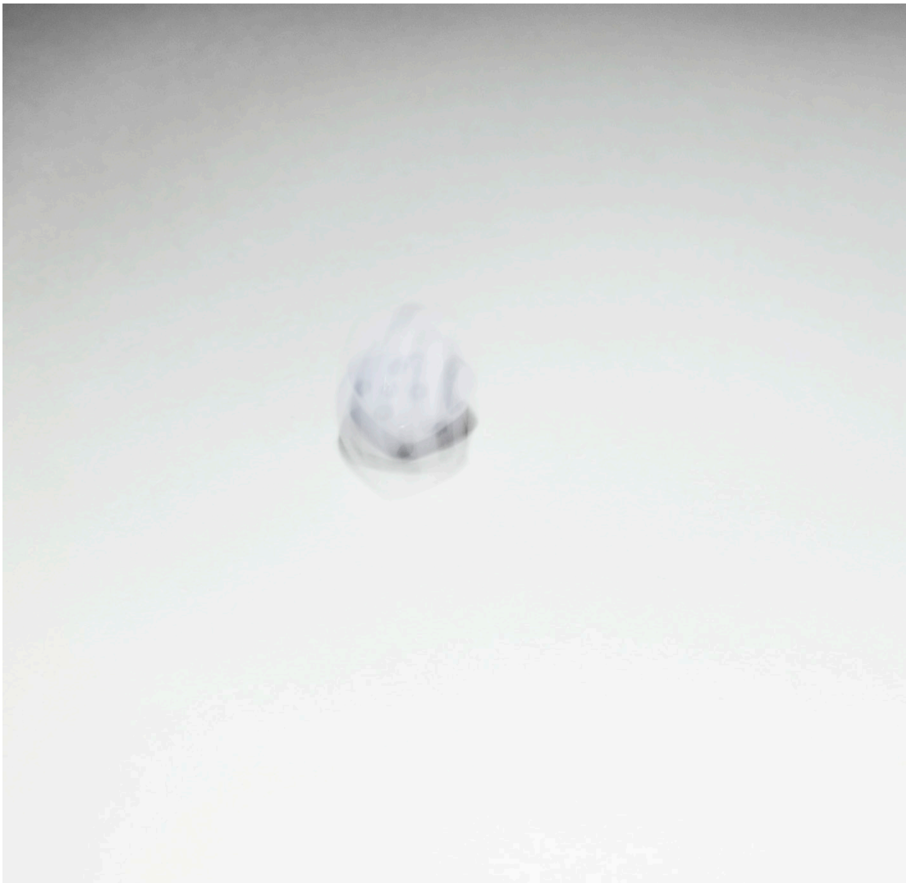

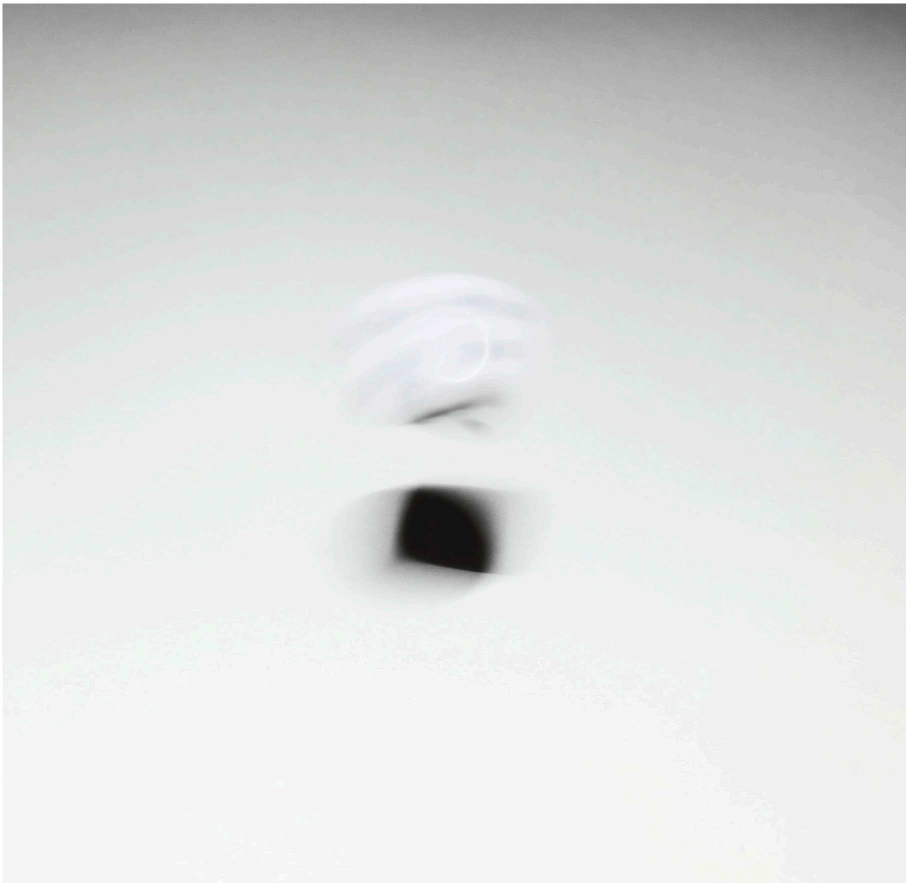

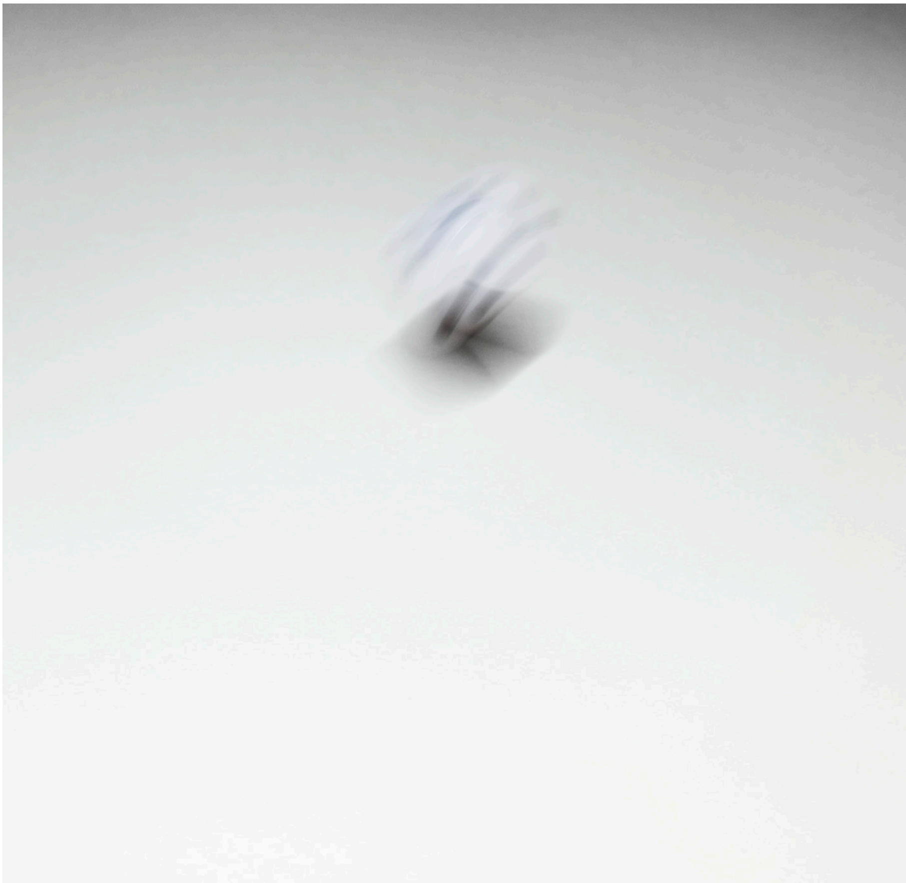

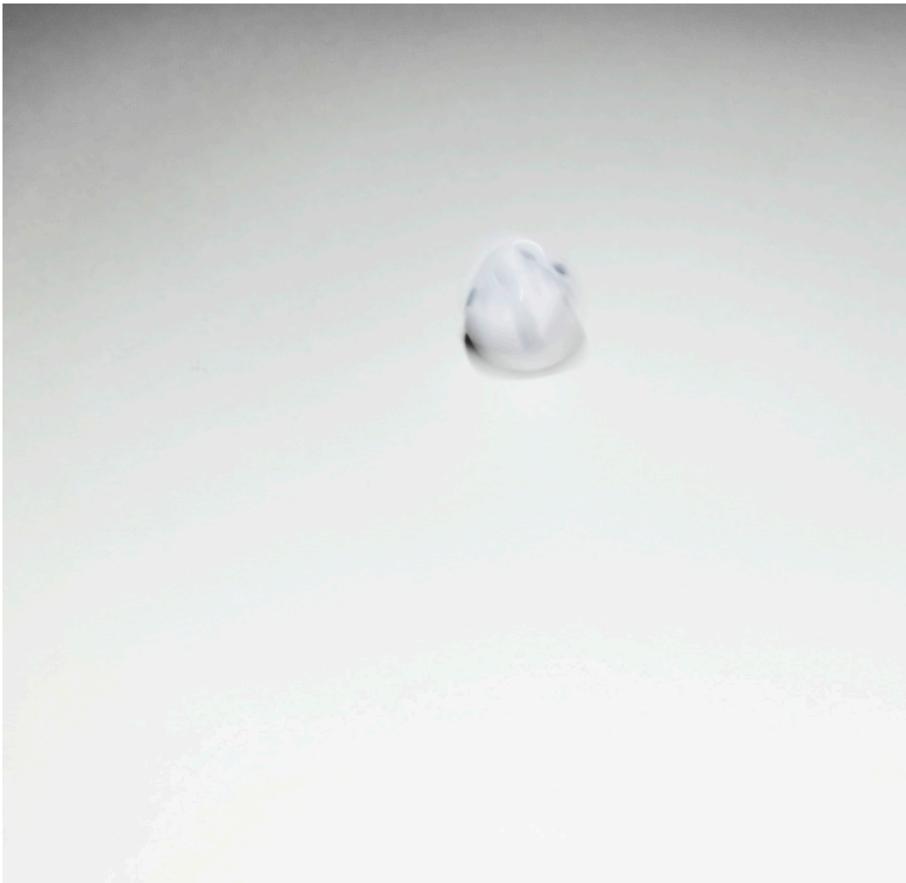

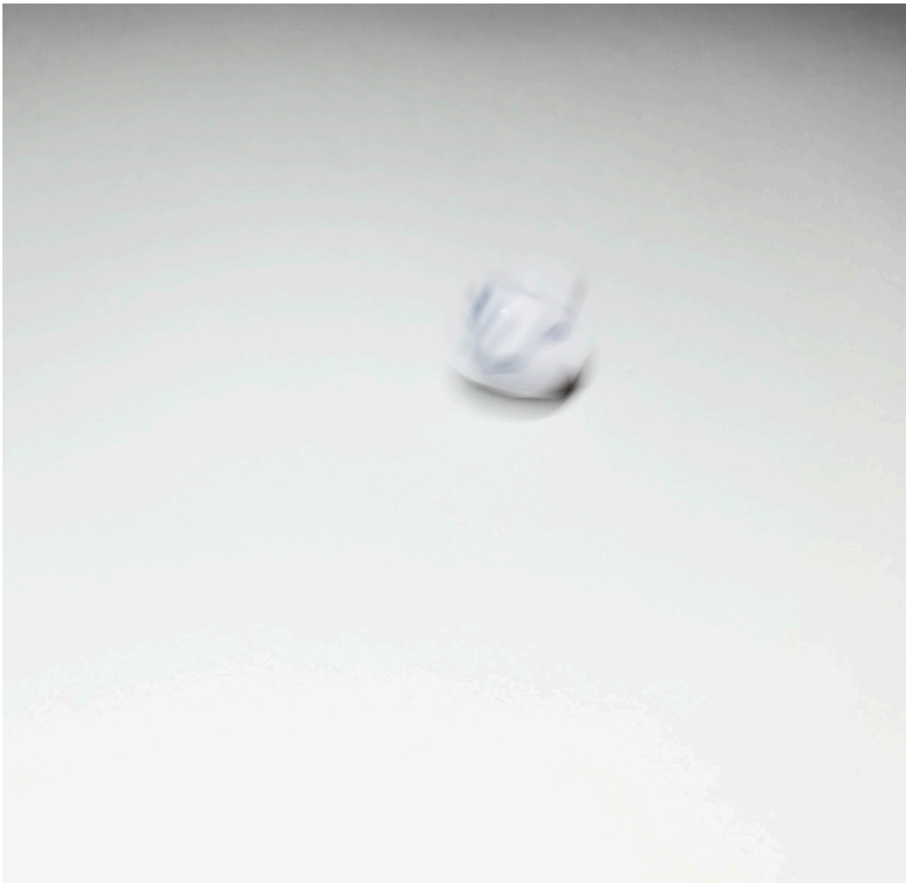

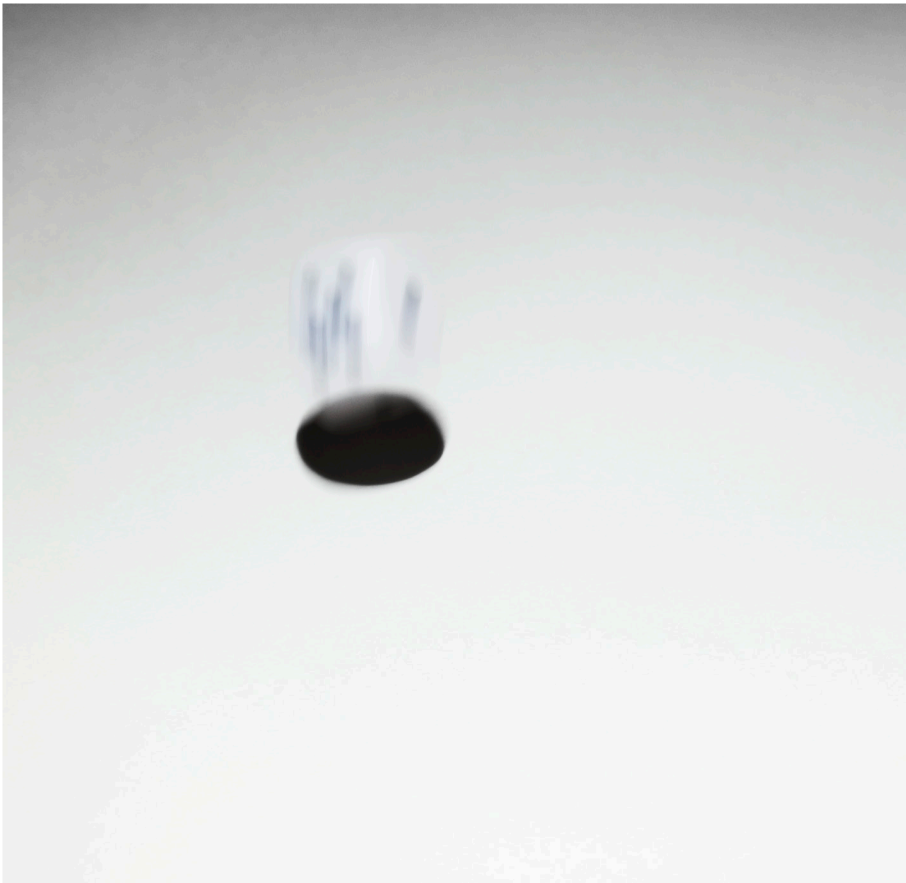

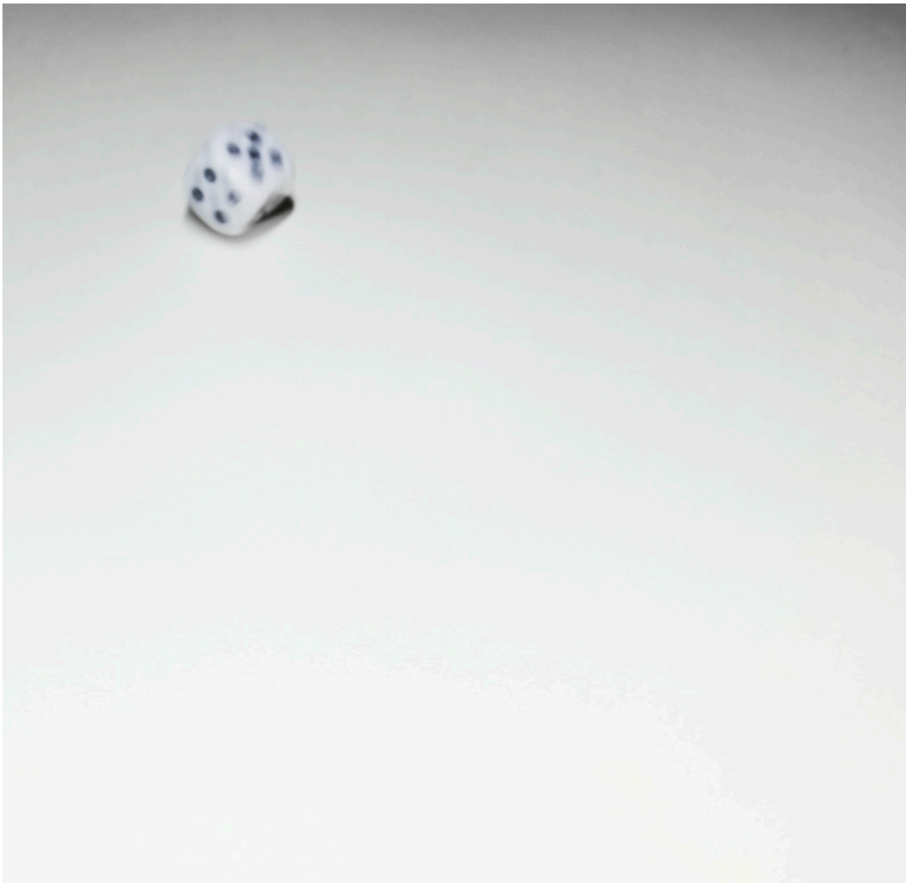

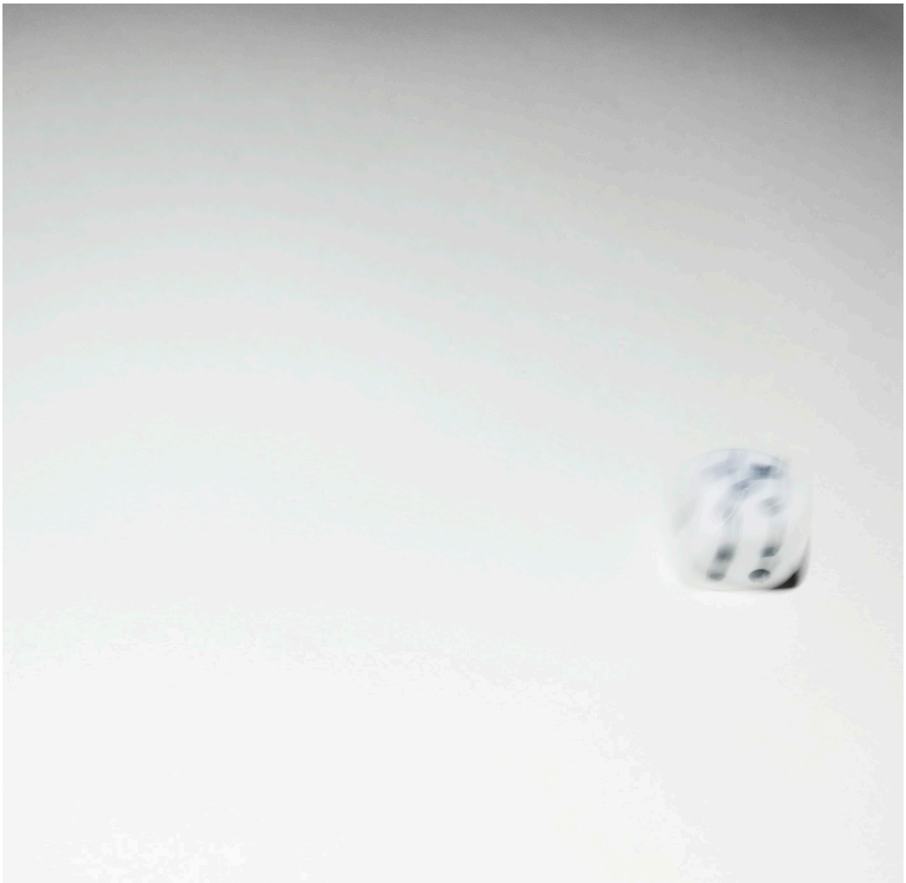

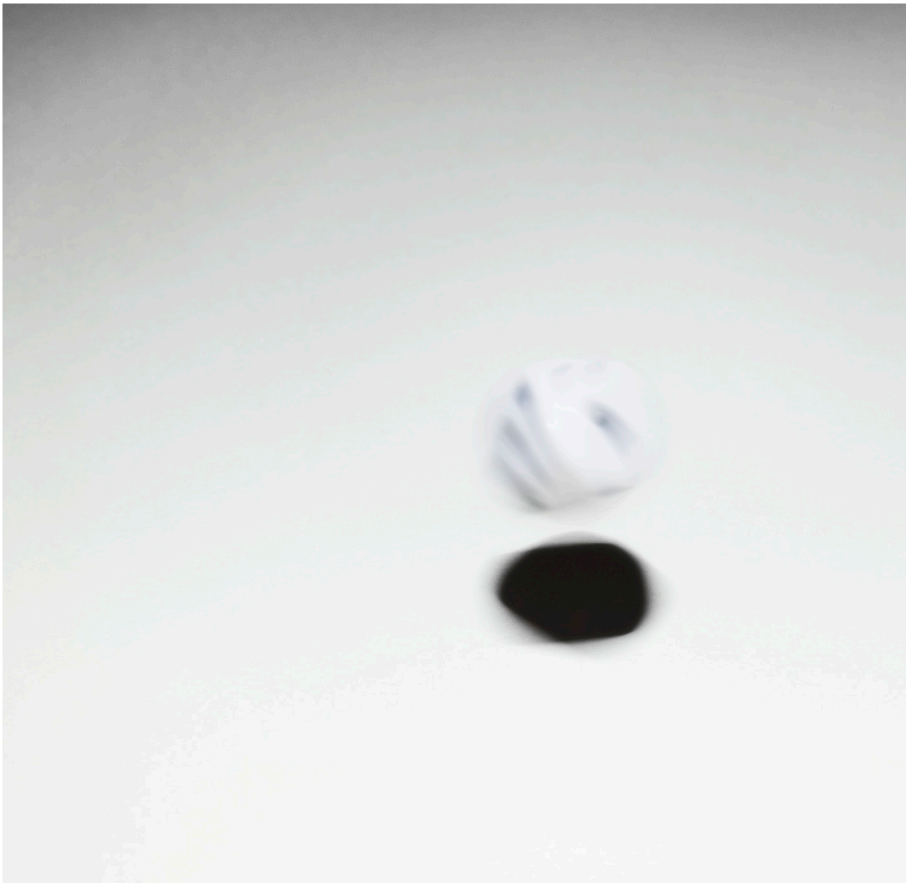

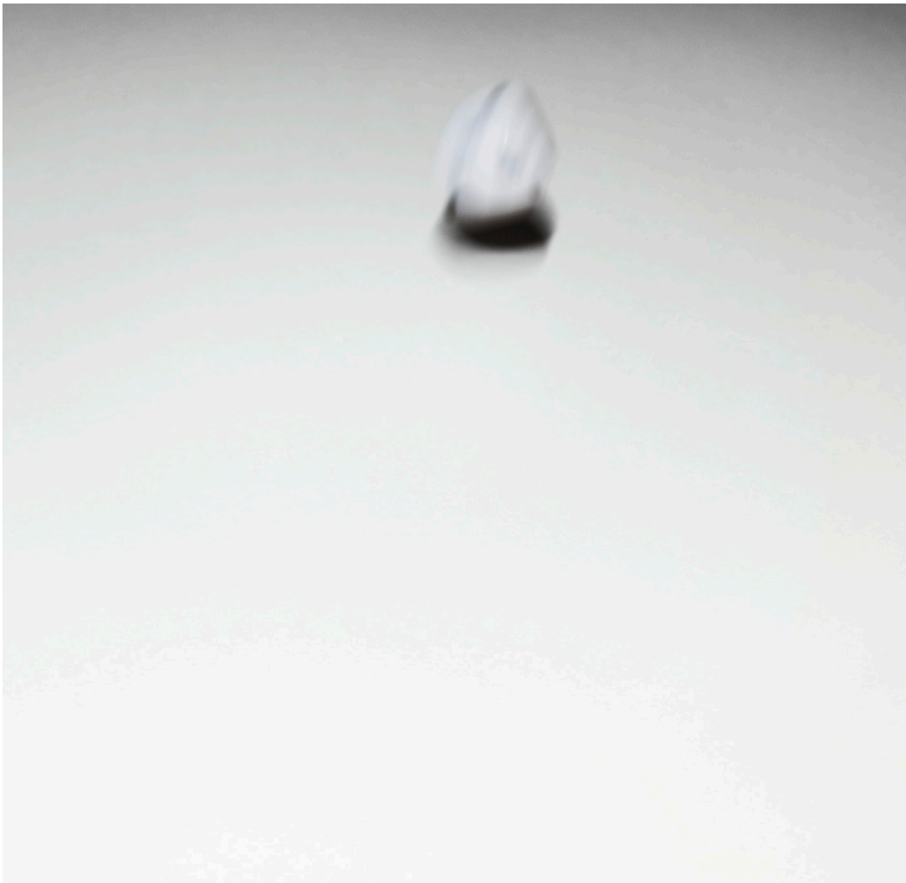

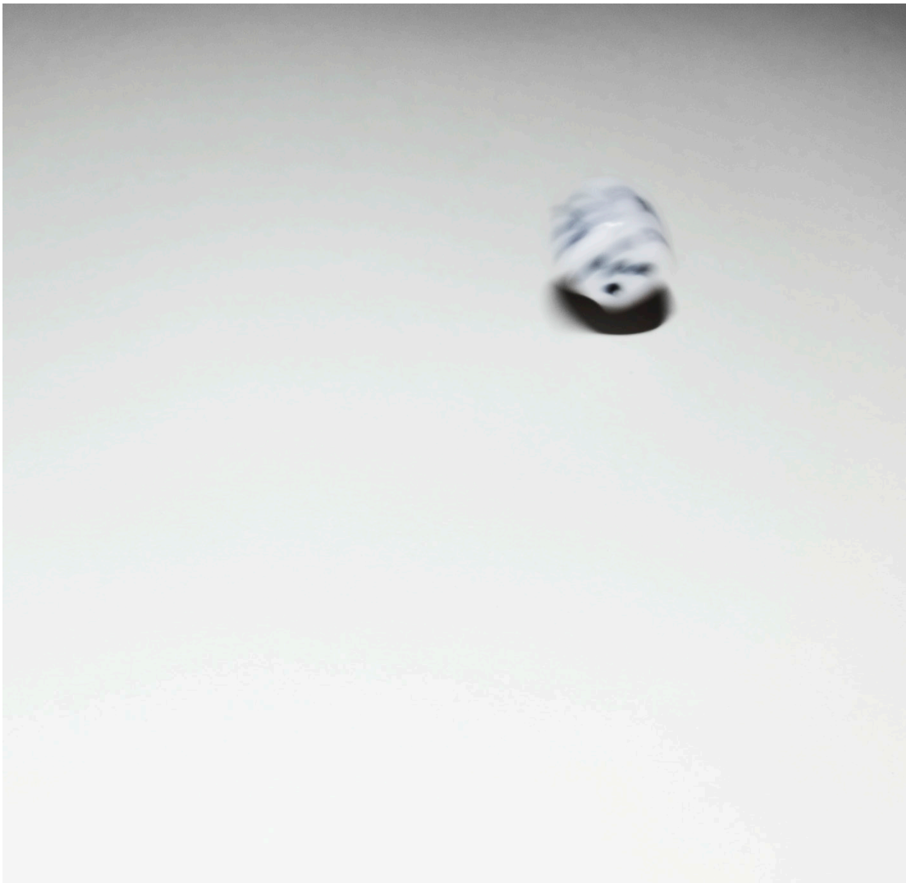

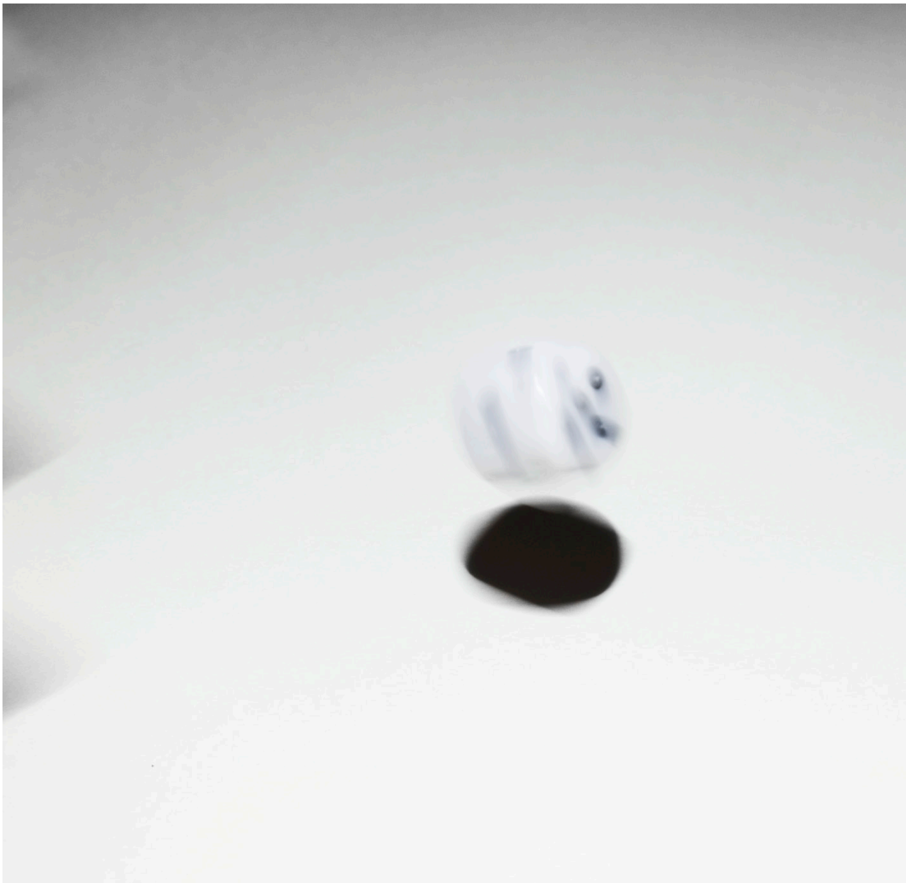

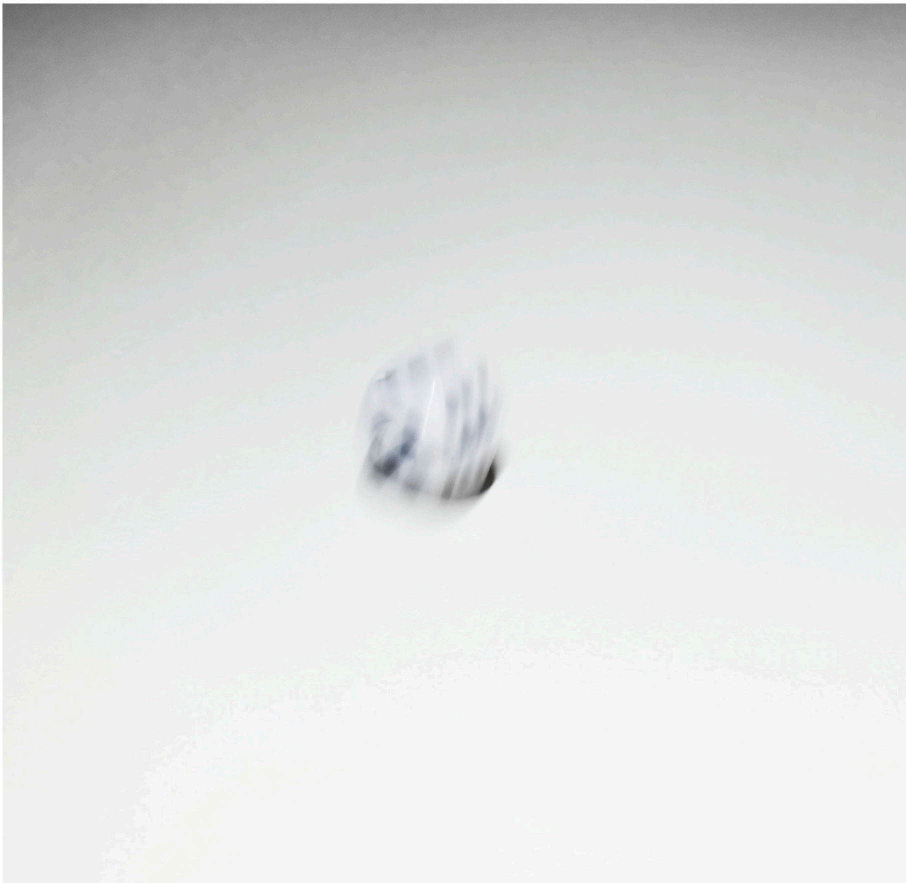

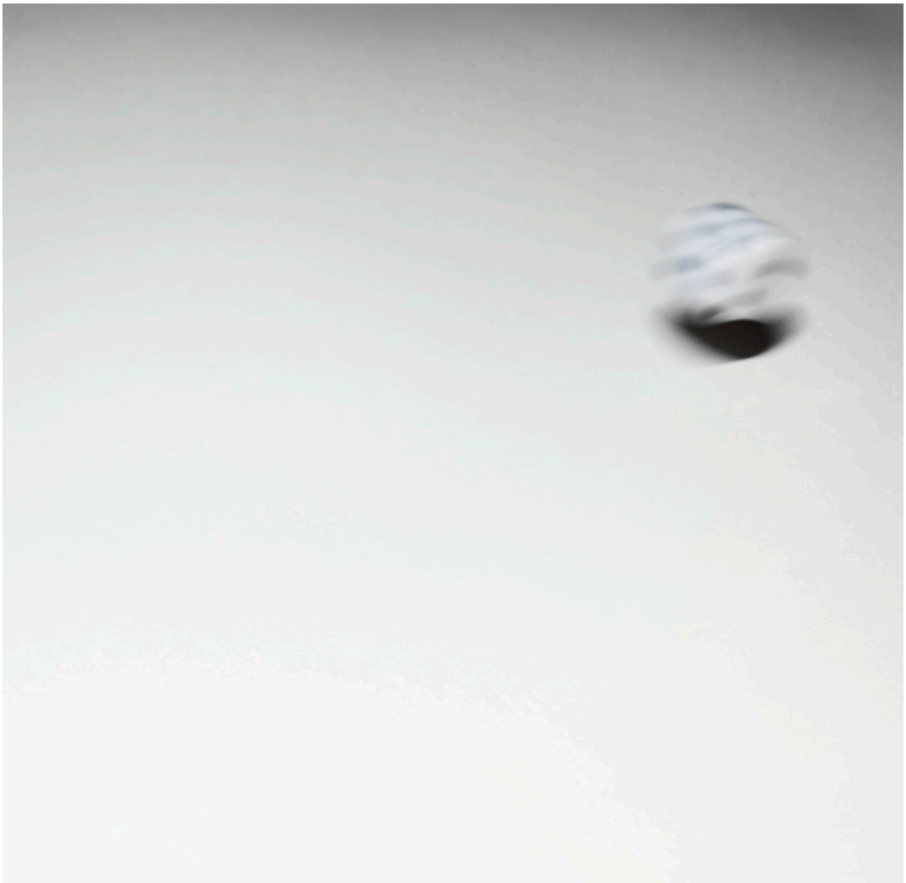

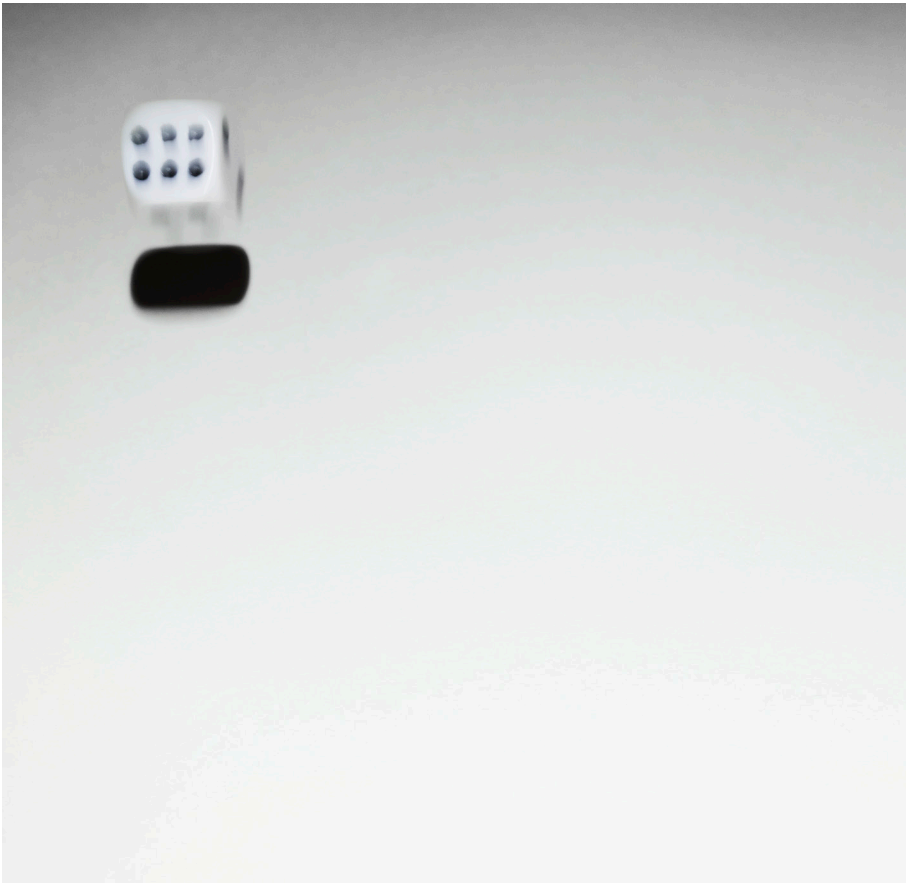

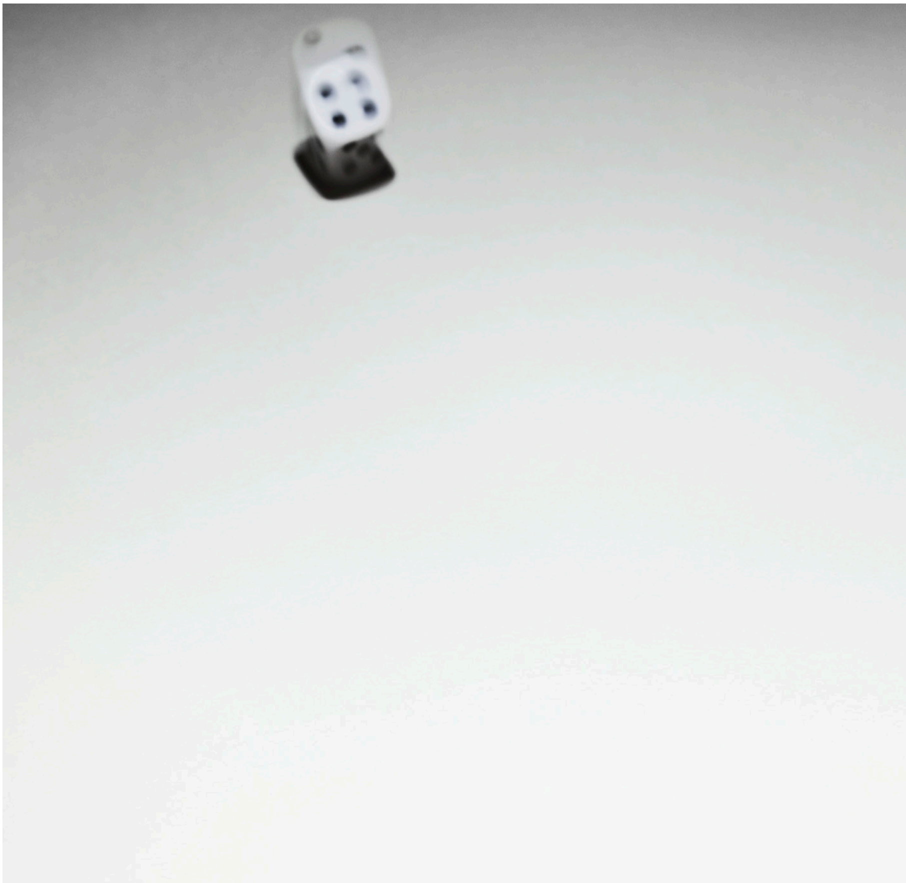

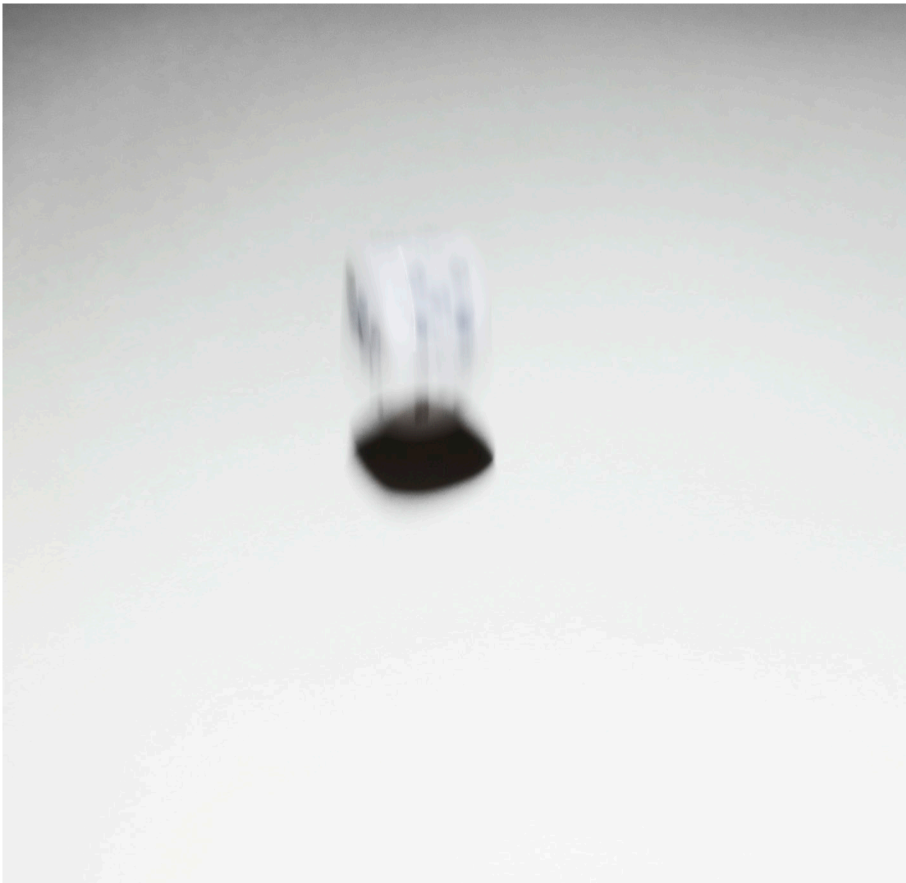

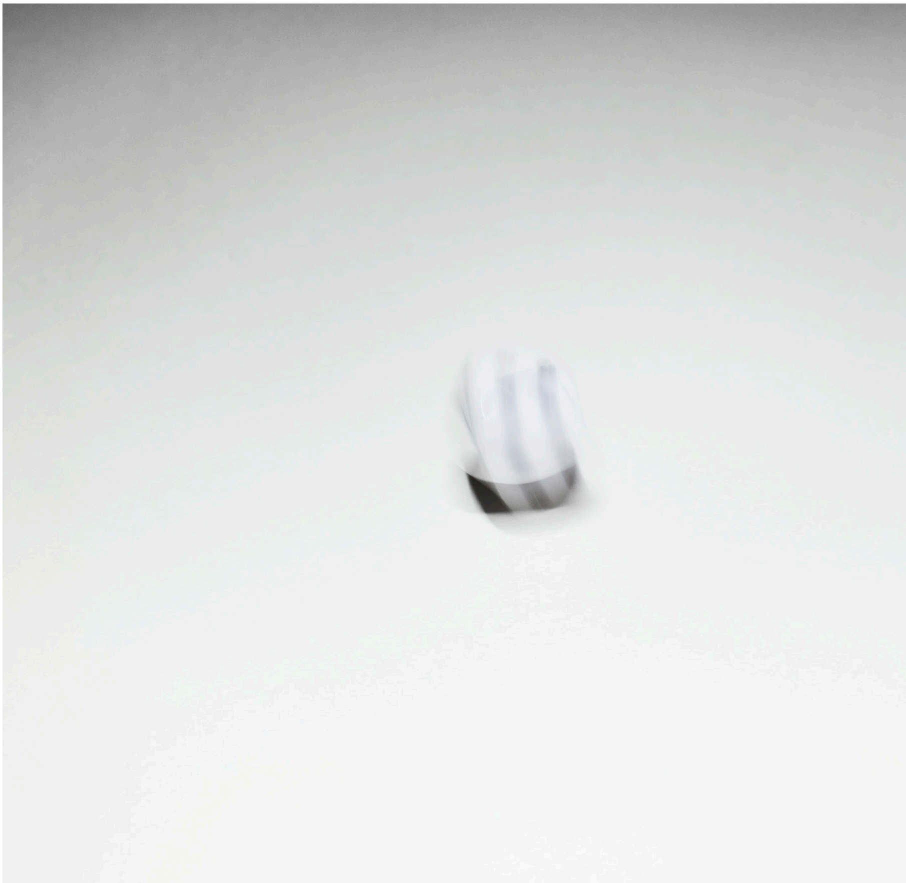

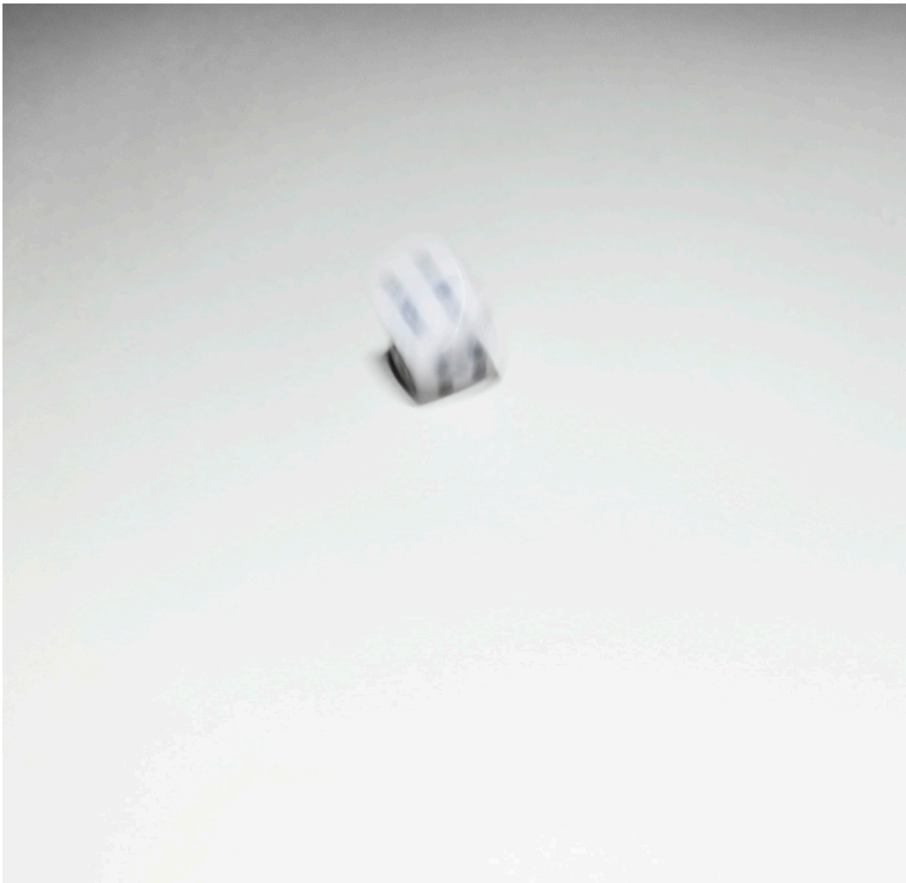

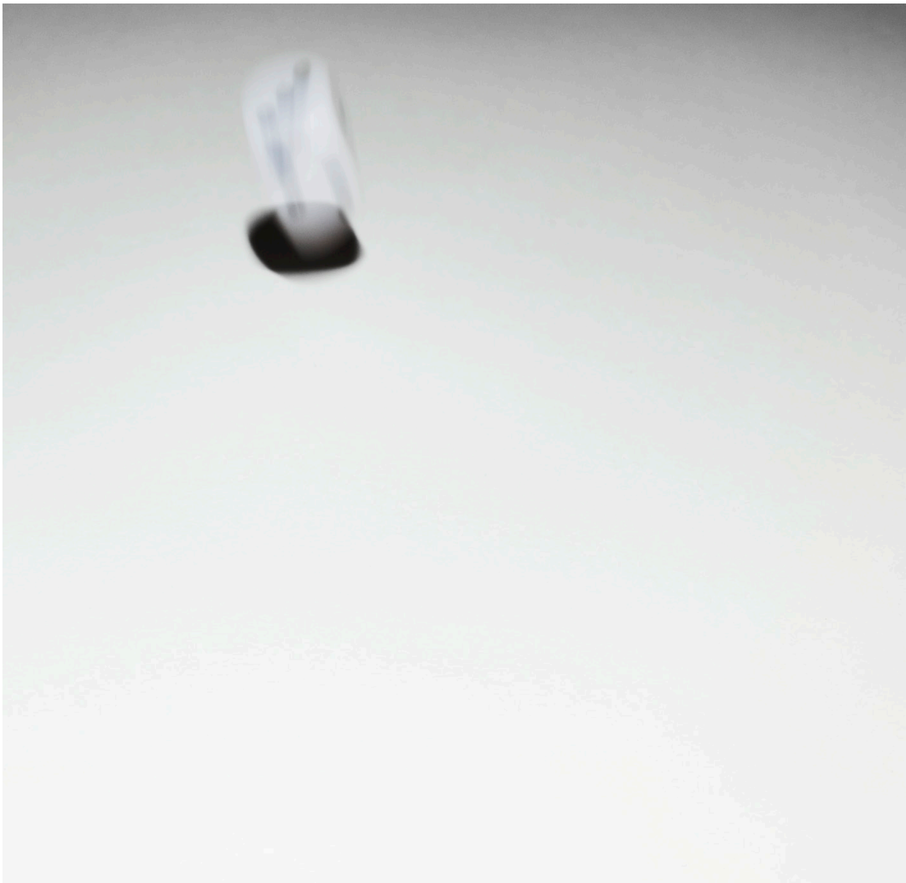

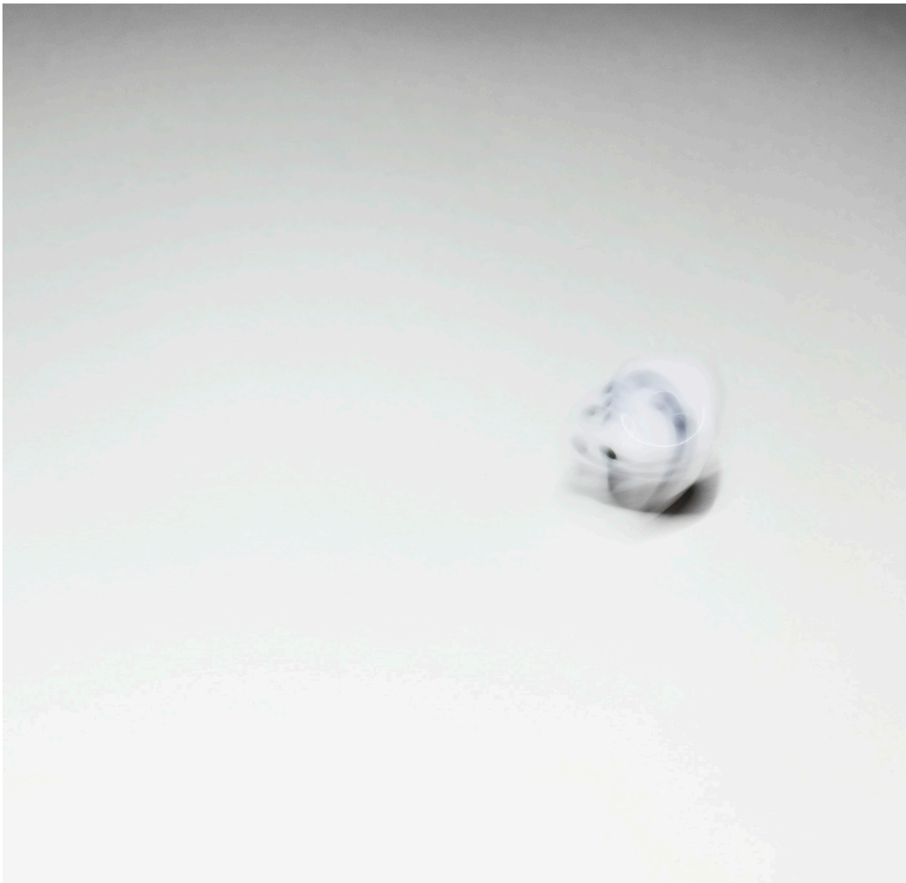

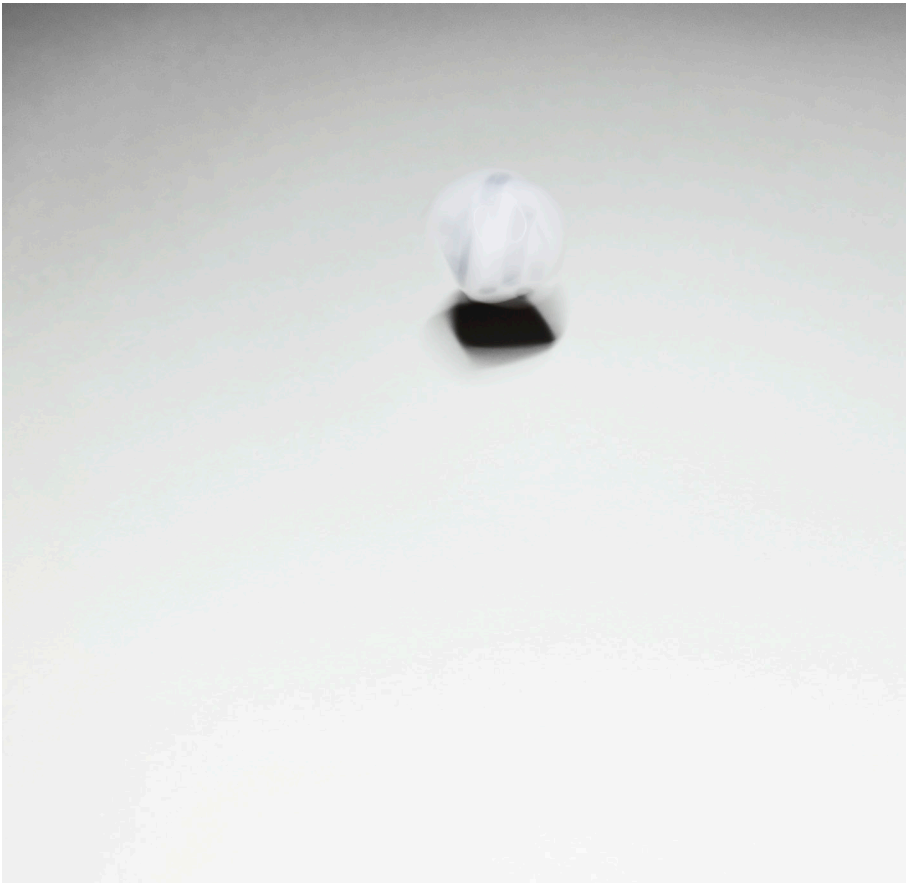

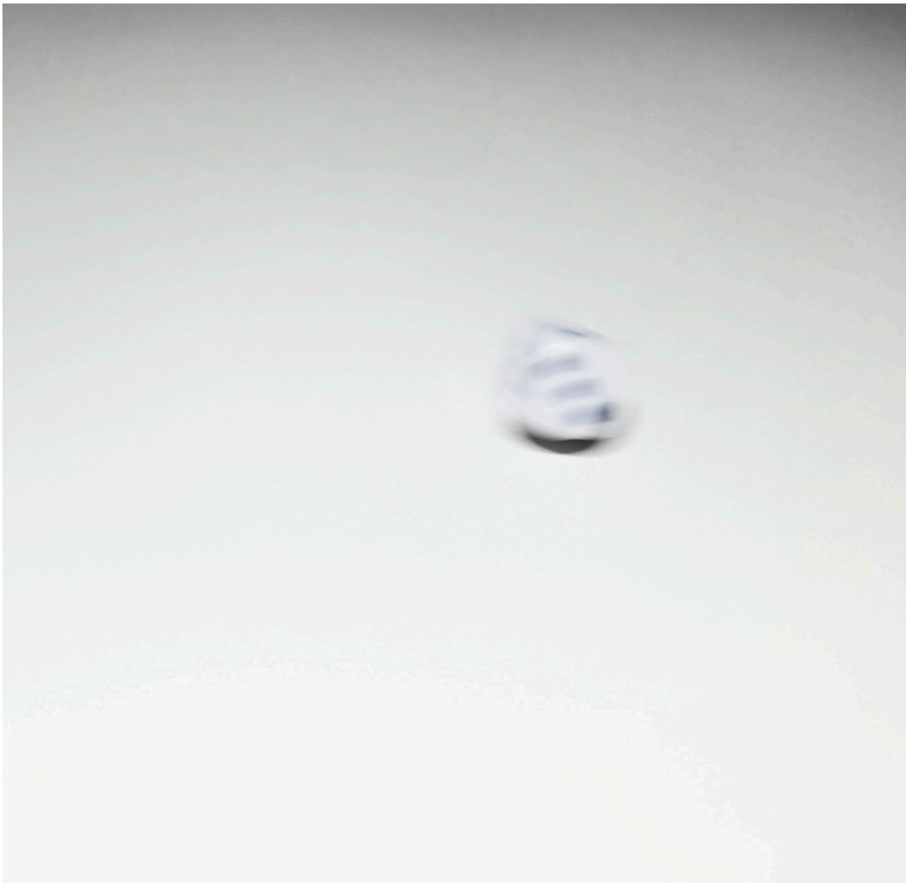

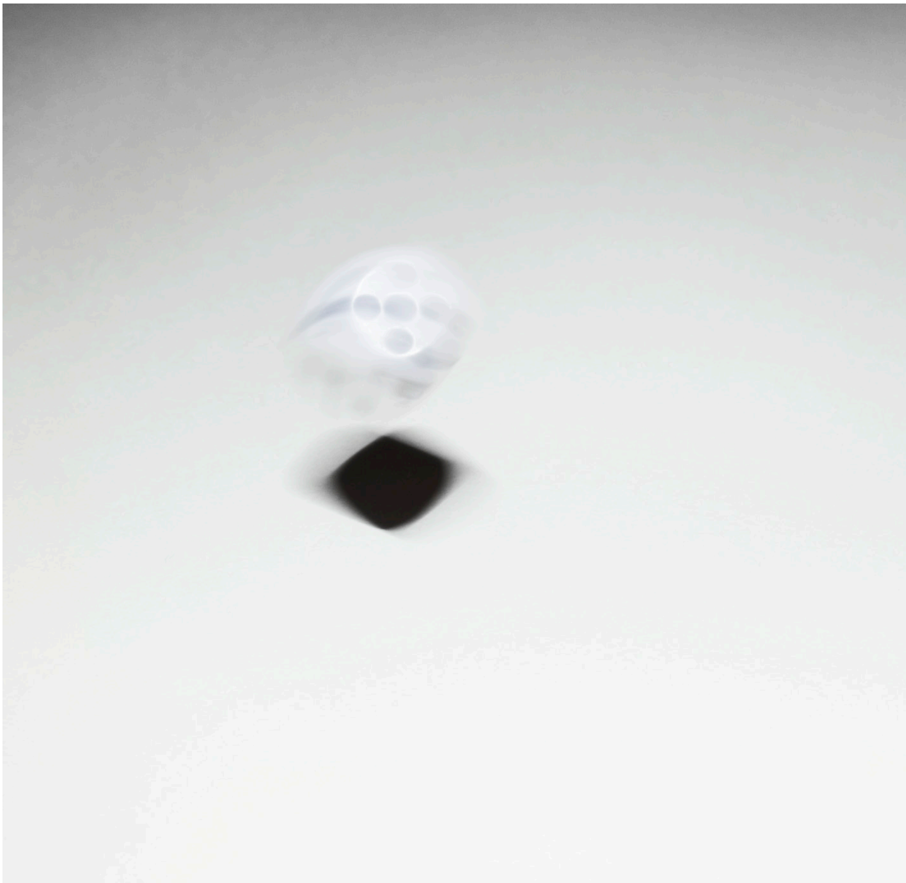

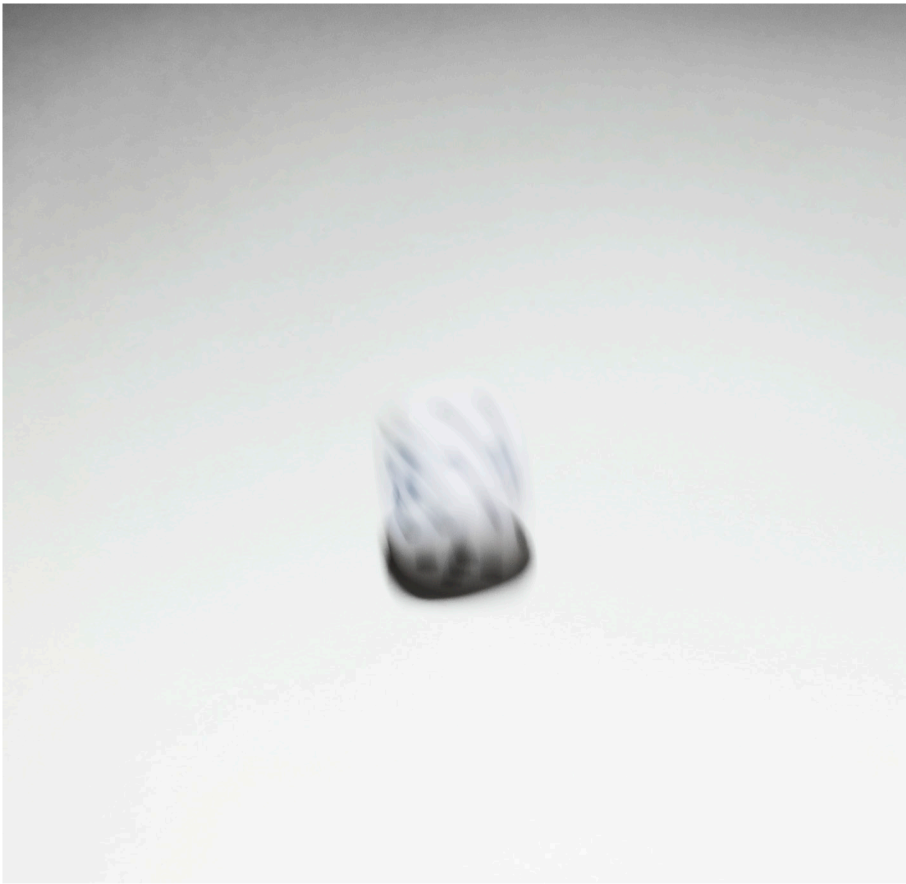

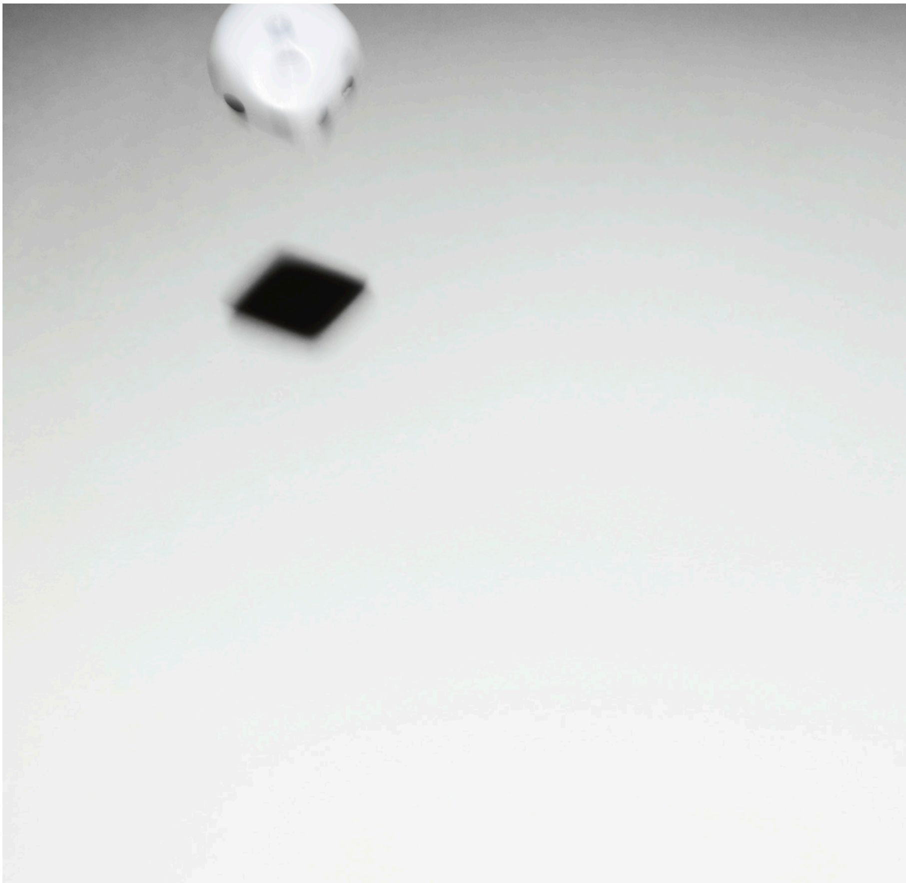

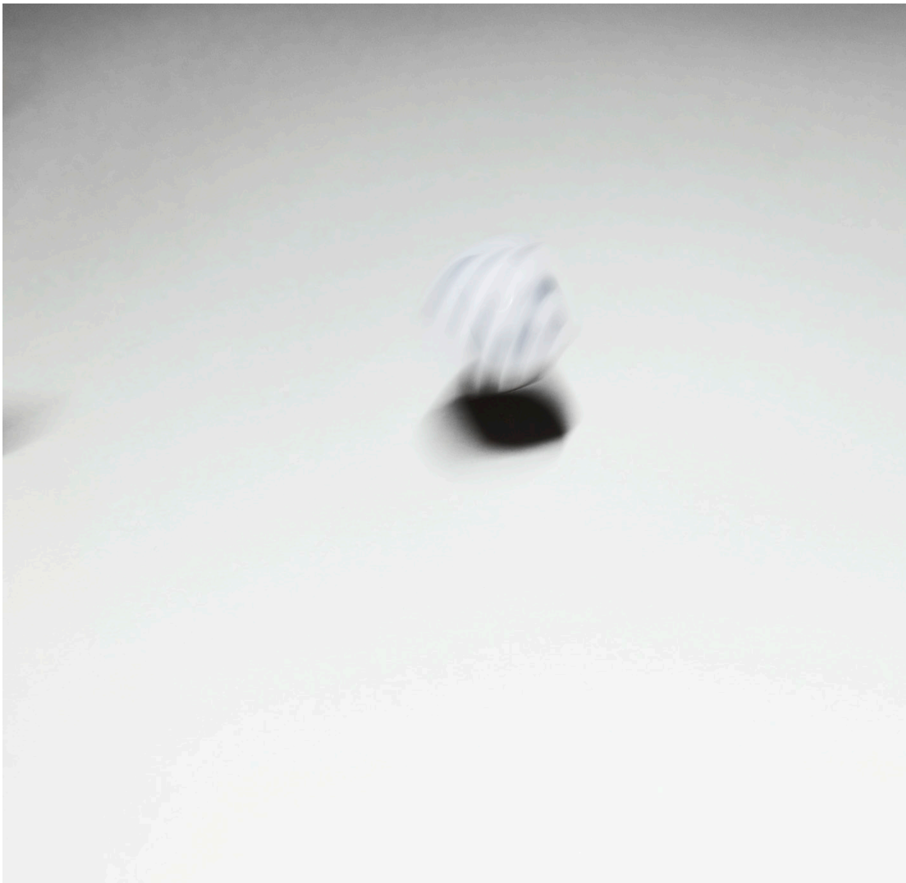

A CONVERSATION

17.11.2016 10:11

Okay. Um. Do you mind introducing yourself?

Sure. Uh. I'm Avaneesh Narla. I'm a senior in the Physics department, so I'll be graduating in 2017.

Great. Um. And I guess we should just get started. I guess we can jump right in. Um. Can you sort of tell me what superposition is?

Um. So superposition is basically the idea that objects do not exist in one state but exist in many different states with certain probability. For example, an electron does not necessarily exist in one position but is actually in many different positions with different probabilities... or the classical example is an electron has either a spin up state or a spin down state. Or a group of electrons have some configuration of up up up down down and so forth. And they might have 50% probability of spin up and 50% probability of spin down for example. Um, that is the basic idea of superposition if that makes any sense.

Mhm. Uhm, yeah I think it does. How is this concept sort of used within the field of physics or I guess quantum physics?

So basically the idea is firstly you want to identify what the states... like you want to kind of... be able to say where the states are in a particular space are, right? So if you know any Euclidean geometry, you can define a dimension in terms of certain directions. So for example, the 2D geometry that we are used to, you can describe in the x-axis and the y-axis. And any point on the 2D geometry I can describe to you by telling you something about where it is on the x-axis and where it is on the y-axis. Similarly in quantum mechanics, what we do is... we say that it is located in some space of possible values. But where that space is located is usually related to... Okay so something interesting I have to preface and this would make more sense is that things are in a superposition until you measure them. Okay? So even though an electron may be in spin up state or spin down state, as soon as you measure it it has to be in one of the two.

Why is that?

That is a very, very good question. It's something that we don't have a good answer to yet. Uh, there's a huge field called measurement theory which tries to explore that and tries to understand what exactly is happening at the time of a measurement. Uh, see that is the thing about quantum mechanics at least in my view and in the view of many others;

it's not the fact that the electron exists in many different possible states that's spooky. You can kind of reconcile that. The spooky part is that as soon as you measure it, you require it to be in one of those states. What it is about measurement and what exactly constitutes a measurement is a very tricky question. And we don't know the answer to it well. Almost anything that we do comprises a measurement. So... you have spin up states and spin down states and as soon as you... it'll be in some probability of them. Maybe it'll be 50% spin up, 50% spin down or maybe 30% spin up 70% spin down and so forth. But as soon as you measure it, 30% of the time it will, like however the probability is distributed, suppose you say 30-70, then 30% of the time it'll be in spin up and 70% of the time it'll be in spin down. So now, when it is on this space and this space is determined by these axes, right? Such that as soon as you measure it, it goes to one of the axes. And the axis that it goes to - the probability of it going to one of the axes is related to how far along the axis it was. So for example, in the case that I just explained to you the probabilities would be 30-70 and one of the axes would be spin up let's say and the other axis would be spin down. And 30% of the time it'll go to spin up and 70% of the time it'll go to spin down. Does that make sense?

Right, so sort of it's... There's like an infinite number of possibilities between the spin up and spin down states. So like if it's closer to the spin up state it'll go to that?

Yeah. Closer is a weird word because it *is* in the spin up state with some probability. It is not always... okay closer to always spin up in a way yeah. Yeah, I would say closer is not a bad word actually. In that respect it's a good word.

Uhm, interesting. You mentioned spooky. Like, is that a technical term?

Haha no, there is a phenomena which is known as spooky action at a distance. But it is not a technical term usually. And spooky action at a distance talks about something else.

I see.

I was just using it as a word.

Uhm, so sort of in the field of quantum computing, there's this concept of a qubit. And from my understanding, qubits sort of also make use of this superposition.

Definitely, that is is one of the *main* things that drive quantum computing.

Could you sort of talk about about like qubits and quantum computing?

Okay so I will preface this– I have a very rudimentary understanding of this. Uhm, but I will explain to the extent that I think I'm able. So in binary logic, going back to this thing spin up, spin down; let's keep spin up spin down, it's a nice thing. In binary logic you have a 0 and you have a 1. And it's always that. Right? Now I just told you that in quantum mechanics, you don't have to be in spin up or spin down. You can be in some combination of them. Right? Now, that means that you have this entire infinite range of possibilities that you mentioned. That means that with just one electron, I don't need it to have two possible states. It can have an infinite number of possible states. In reality it becomes more difficult, and you have to kind of partition these different possible state regimes, and you have to account for error correcting and so forth. So we'll have a finite number. But, a very large finite number... Now, earlier whenever you'd wanted to do a particular computation you could only have these bits be in one state. But now since you can have these bits be in so many different states, the computing power that you're getting out of it is much much larger. Something else that happens is that you *do* have randomness now. Now something in computing that's a big problem is that you cannot have randomness. It's artificially generated; randomness is not a thing. But now you can have randomness. Uhm, these are the– This is my rudimentary understanding of it, but because of these two you can make use of lots of algorithms? in order to do much more efficient computation. Does that make sense?

Mhm. So sort of the main concept is that you can go from having two states to multiple states through the idea or concept of superposition?

Exactly.

I see. Uhm, what are other applications of superposition that you know of?

I mean, superposition is universal. Like I mean, I think it's safe to say that almost everything that– Superposition is one of the fundamental tenets of quantum mechanics. Almost everything that follows from quantum mechanics is kind of in some way based in superposition. There are electronics that you're talking of that are completely quantum mechanical. Uh, you have lots of other devices, medical devices, imaging devices, uh cameras, photocopying devices; lots of different things. Uh solar cells; all of these things are to some extent using superposition. The tricky thing is they're using superposition to a very, in a very abstract way. In a very continuous way. So very rarely do you have this case that it's a spin up spin down and it's choosing between the two and you can nicely write down the probability between two states and then say it's going to choose one of the two. Quantum computing is one of those cases, but in most cases– For example a hydrogen atom. We are talking of the electron existing in some like probability distribution, we call it a probability cloud. Uhm, so it's very difficult to pinpoint and it's very difficult for us to use superposition. It is used, I take that back. It is used. But, it's less– it's at that point just considered probability right? So, in fact if you take that it's almost fundamental in chemistry; all chemical reactions and kinetics that are developed and binding theories and all that stuff. So, I would say it's pretty ubiquitous. It's just in a different form rather than just your discrete plus minus, it's more of a continuous probability cloud that exists and people are now talking about the probability of an electron existing in a particular region and then saying, and then using that in order to do other sorts of calculations.

And that's sort of where you get like the s, p, d, f orbitals.

Yeah exactly, the s, p, d, f orbitals are basically the probability– dense probability regions.

I see. Uhm, something that I'm interested in as well is sort of the temporal aspect to things. Uhm, you mentioned earlier that like you don't– like when you sort of– an object is in superposition until you observe it? At which point it becomes uhm, one of the states? And, yeah I was just wondering like, are there any other interesting temporal aspects to this phenomena that you haven't thought about.

Oh, there is one really interesting one. Well I– Before I say that, there is something where there uh– should be understand regarding an analogy of the dice for example. The dice are a really good example; it's a quantum superposition between six states. But something to realized is– the superposition exists for the dice that have been rolled but you haven't seen. Right? Where it is– so, technically dice are not quantum mechanical. But, uhm, the fact is that when you roll a die and you have rolled it but you haven't measured it yet, then you don't know what state it is. It could be in many different states. And as *soon* as you measure it, it is in one of those states. So if you were to draw a certain probability distribution, you could say that it's there. Now, the thing about quantum mechanical objects is that they are in such a state all the time.

Mhm.

Right? Uh that they operate on the principle that they are in multiple states at the same time. Uh it's not that they *could* be in multiple states; they *are* in multiple states.

Hm.

You measuring them forces them to be in one of them. But as I said, that is the weird part. We- that should not be looked as at crucial. The *crucial* part, that uh the intrinsic nature of it *is* that it is in multiple states. So that is something that should be realized when making that analogy. It is a good analogy but you just have to realize what it is you're connecting it to in quantum mechanics. Regarding time, uh there's a very nice paradox in quantum mechanics known as Zeno's Paradox. It's not exactly a paradox, but it's known as Zeno's Paradox. Uh, do you know the classical Zeno's paradox?

Uh, not off the top of my head.

Okay, so the classical Zeno's Paradox is suppose I shoot an arrow, okay? And the arrow needs to hit a particular distance, lets say 1 away. Now in half the time, it'll cover half the distance. In another half of the time, it'll cover half of the distance.

Oh yeah.

Right? And at every half interval, it's always covering half of the distance. But, 1 over 2 plus 1 over 4 plus 1 over 8... you can keep adding, but you'll never hit 1. Right? If you keep adding smaller and smaller intervals. Why is that? Like I mean, but it hits the thing, right? Uh and that has a long logical back tale. Cantor came the idea of uh... and the idea of countable and uncountable sets came in. It was a very interesting field. Anyway, Quantum Zeno's Paradox is different. And it is with a different phenomena. So, when I told you that states exist in a particular probability distribution, that distribution does not need to be constant in time. That distribution can change over time. In fact, almost always it does. It evolves over time. It's usually in a phase, so that means that it's cyclical. It just goes up. It just uh, if you just imagine a circle of all these possible states, then it keeps going around the circle. And comes back after a certain time period. Right? Uhm, now suppose there is a quantum mechanical object that as soon as you measure it, it'll be in one of the states. But then, as soon as you leave it, it'll start progressing again. So, suppose I just keep looking at it... Does that mean that i'll just not evolve? Like if I look at it every 1 minute, then I can start observing it with a certain probability distribution. Suppose I look at it every 30 seconds, then I can start measuring it at those particular time points.

Right.

Suppose I start shrinking the time period continually. Then at one point, it's like I'm not– the time dependence certainly disappears because I'm just observing it. If that makes any sense. Uhm, and that's paradox. I'm not doing a great job of explaining it but...

I think I understand.

Okay. So that is a very interesting conundrum in quantum mechanics. But it can be easily resolved if I can remember just by– Actually the fact is that it's not a paradox. The fact is, yes it does not evolve. I think that was the resolution.

Hm.

Which is very very non-intuitive because you would expect the state to evolve over time.

So it's sort of counter to... So when you constantly observe it it does not evolve.

Yeah, I think that was the resolution to it.

Huh. So when you're observing an object that's superposed, does that mean that the object is in fact in that state. Or does that mean the object, while you're observing it, is in that state while also being in all these different states.

It is in one of the states. As soon as you observe it, you force it to be in one of the states.

I see. That's really interesting.

Yeah, it really blew everyone's mind. Uhm, that's why Einstein was very freaked out by it. And that is why he had this particular conundrum which he called spooky action at a distance. Which is what I was referring to earlier. Which is that– now quantum mechanical objects can be entangled.

Right.

Okay, so this comes from a basic conservation of momentum. Okay? Now conservation of momentum has to continue. Okay?

Mhm.

Now you might say, “Okay, so I’m going to create two different states. One of which will have left momentum and one of them will have right momentum.” And then– sorry, two different states, the some of which will have to have left and right. Right? But, their momenta are also in probability– some probability distribution. So, you want their sum to be constant. But you want each of them to lie in some particular probability distribution. Which would mean that as soon as you know one, the other is forced to be some other value that can be calculated as the difference. Okay, fine. Now, what if I take it– take one of these things really really far away. I take it to another galaxy. And I measure it. And I force it to be a certain momentum. Then, there are two possibilities. Either, this thing– the one that is left here doesn’t know what momentum it has and thus adopts some other momentum value. That the some of the two will add up to more or less than the initial momentum. And that’s a violation of principle– basic ideas in physics. So that will be a violation of conservation of momentum.

Right.

The other possibility is that it *does* know what the other momentum value that was measured was. And thus it takes total minus that value and it conserves momentum. But, if that takes even a short period of time to happen, that would mean that there is violation for a certain period of time. These things are two galaxies away. It takes a lot of time to go from one galaxy to another; for information to travel from one galaxy to another. So, how would it know? And the fact is it *does* know. And it’s very crazy that it does know, but it knows. So, you can show that in fact, it cannot be used to convey information. But you can– it has been demonstrated. In fact, only in 2014 was it demonstrated with no strings attached that that does happen.

And what are the implications?

Uhh, the implications mainly are that quantum mechanics is correct. Uh, that is the biggest thing because a lot people felt that, you know something like that should not happen because locality. Like things should only be aware of things around them. Things should not have this, you know like weird connection with something that's a galaxy away. That just makes no sense. But, that is at the heart of many different things in quantum mechanics. There something known as the Pauli Exclusion Principle which comes from that, and the Pauli Exclusion Principle leads to how you fill up orbitals in an atom. And thus everything in chemistry follows from the Pauli Exclusion Principle. So it's a very very basic idea in quantum mechanics: quantum entanglement. And you could have a lot of things; basically a lot a lot of things follow from it. But, on a more direct use of it, it's being used for cryptography now. It's been used for quantum teleportation and communication of signals. For example right now, China built this satellite and it's communicating signals by quantum entanglement from– and it's a lab in China and a lab in Vienna. And they will exchange signals by quantum– by entangling them. And nothing– so basically because they're entangled, anything else that tries to measure it will just get garbage because it does not have the other state.

Huh. That's an interesting form of cryptography.

Yeah, it's flat out secure. There's no way you can know what the information is unless you were the person who has the other key.

And that's just by physics.

That's just by physics yeah. Obviously it's a huge engineering challenge, but the basic principle is fundamental physics.

Hm. Woah.

Something interesting that I would encourage you to also look into is the fact that in classical *and* in quantum mechanics, time does not have an arrow.

Okay. What does that...

It means that time is reversible. You can move backwards in time or forwards in time and you would mostly be fine. As I said you're just moving in a circle. In classical mechanics as well, that is the basic idea; you just move around in a circle.

So, sort of in classical mechanics, time is defined by the cycle of
uh quantum superposition? Like how how that changes?

In classical mechanics?

Or sort of, I'm just not...

Classical mechanics precedes quantum mechanics. Or is one limit of quantum mechanics in other words. But, classical mechanics basically the idea is that for example if you are a ball that's split between two hills and if you let the ball roll, the ball goes down; it goes from one hill to the other hill and comes back down. In the absence of friction it just keeps going up and down between the two hills. And so, if you were to look at the ball at one point in time, you could go forward in time or backward in time because you have complete information.

I see.

Similarly in quantum mechanics, other than measurements, you can go forward or backward in time. There is no problem. The problems that actually emerge like the fact that we do experience an arrow of time is more related to statistical mechanics. It's a very, very tricky and deep thing that takes a lot of time to really grasp and even I– this is what my work is based on and I don't, I can't claim to have a complete understanding of it.

So what is your work currently?

My work currently is looking at signalling in bacteria. And how bacteria can exchange signals and interact with each other. With not only members of its own species but members outside its species. So for example right now we are working on a problem where a crowd of bacteria want to communicate their local cell density, which is something that bacteria do in real life. In the class of, in the process we are basically like it *has* to follow into one of these things. It's very difficult to identify and isolate the processes in experiment and even when it is possible, people don't know where to go. So we've found a theoretical result that kind of says if this particular signalling happens, then it has to be under these conditions. So that's what I'm doing.

And how does that relate to what you were talking about with either quantum or statistical mechanics?

So it's statistical mechanics. I mean, there's so many things but one of the things for example is regarding diffusion. And diffusion is a statistical mechanics form of phenomena. Uhm, and lots of other things like statistical mechanics can be used to kind of explain how things evolve over time if they interact with each other. What those interactions are and what are those things are can literally be anything and that's kind of what we do. We put them as bacteria, we put them as signalling molecules and stuff like that. Or the signalling molecules in the environment and stuff like that.

Going back to the topic of sort of the fact that time has no arrow...

Oh, in quantum mechanics and classical mechanics there is no arrow of time, yeah.

Okay, how is that conclusion sort of arrived at? Is it sort of just a purely logical conclusion?

So it is a purely logical conclusion. And the idea is that if you, well it also you can get it in uh normal life as well and I'll get to that in a bit. But the idea is that if you give me the position– if you give me the complete information of a system. If you give me a snapshot of a particular system, then by looking at the time evolution, I can see how it is going to go forward or backward in time. It's symmetric. Right? Time is a scalar value so it can have negative value; that's perfectly fine. It's kind of arbitrary where you choose t is equal to 0 is. So you could just go back in time if you wanted to. And you see that happening actually. For example pendulum: if you removed friction and everything else, then if you just let a pendulum swing, then if you told me the velocity and position of a pendulum at a particular time, I could tell you not only all the states it'll be in the future, but also all the states that it was in the past.

And the same I think could be said about a clock?

Yeah, exactly. A clock goes around in circles. So if you tell me that it is 2 'o'clock right now, I can tell you that one hour ago it's 1 'o'clock. And one hour later it'll be 3 'o'clock. I know *exactly* how it's going to move.